NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

A SURVIVABILITY ASSESSMENT OF THE TRANSFORMABLE CRAFT IN AN OPERATIONAL ENVIRONMENT

by

Huntley J. Bodden

June 2010

Thesis Advisor: Gary E. Horne
Second Reader: Thomas W. Lucas

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.				
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** June 2010	**3. REPORT TYPE AND DATES COVERED** Master's Thesis		
4. TITLE AND SUBTITLE A Survivability Assessment of the Transformable Craft in an Operational Environment				**5. FUNDING NUMBERS**
6. AUTHOR(S) Huntley J. Bodden				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A				**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ____________________.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited				**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

Seabasing is developing as a dominant concept for military operations in the 21st century and will be at the core of joint operations abroad. To enable an effective seabase, the Office of Naval research is leading an effort to design and develop a seabase connector known as the Transformable Craft (T-Craft). The T-Craft is intended to provide "game changing capabilities" for seabasing operations—substantially outperforming any seabase connector in the Navy's current inventory. Through the use of simulation, state-of-the-art design of experiments, and advanced data analysis, this research modeled and analyzed over 430,000 seabasing missions by varying the number of T-Craft, their capabilities (e.g., speed), the types of weapon systems carried, tactics, escort mixes, and threat level in order to determine which combinations obtain the highest survivability and throughput rate for the T-Craft. As a result of the research and analysis, the following were found: (1) the presence of escorts (at least two LCS in the scenarios we examined) is critical when a threat exists; (2) the operating speed of the T-Craft must be determined by the operating capabilities of the escorts; and (3) the shoreline threat remains a critical area in ensuring T-Craft survivability.

14. SUBJECT TERMS Transformable Craft, T-Craft, Sea base, Sea base Connector			**15. NUMBER OF PAGES** 118
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release; distribution is unlimited

A SURVIVABILITY ASSESSMENT OF THE TRANSFORMABLE CRAFT IN AN OPERATIONAL ENVIRONMENT

Huntley J. Bodden
Major, United States Marine Corps
B.S., University of Florida
M.S., University of Maryland University College

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
June 2010

Author: Huntley J. Bodden

Approved by: Gary E. Horne
Thesis Advisor

Thomas W. Lucas
Second Reader

Robert F. Dell
Chairman, Department of Operations Research

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Seabasing is developing as a dominant concept for military operations in the 21st century and will be at the core of joint operations abroad. To enable an effective seabase, the Office of Naval research is leading an effort to design and develop a seabase connector known as the Transformable Craft (T-Craft). The T-Craft is intended to provide “game changing capabilities” for seabasing operations—substantially outperforming any seabase connector in the Navy’s current inventory. Through the use of simulation, state-of-the-art design of experiments, and advanced data analysis, this research modeled and analyzed over 430,000 seabasing missions by varying the number of T-Craft, their capabilities (e.g., speed), the types of weapon systems carried, tactics, escort mixes, and threat level in order to determine which combinations obtain the highest survivability and throughput rate for the T-Craft. As a result of the research and analysis, the following were found: (1) the presence of escorts (at least two LCS in the scenarios we examined) is critical when a threat exists; (2) the operating speed of the T-Craft must be determined by the operating capabilities of the escorts; and (3) the shoreline threat remains a critical area in ensuring T-Craft survivability.

THIS PAGE INTENTIONALLY LEFT BLANK

THESIS DISCLAIMER

The reader is cautioned that the computer programs presented in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ACV	Air Cushioned Vehicle
ARG	Amphibious Ready Group
ASW	Anti-submarine Warfare
BAA	Broad Agency Announcement
CA	Cellular Automaton
CNO	Office of The Chief of Naval Operations
CONOPS	Concept of Operations
CSG	Carrier Strike Group
CSV	Comma Separated Values
DoD	Department of Defense
DTA	Defense Technology Agency
ESG	Expeditionary Strike Group
GUI	Graphic User Interface
HQMC	Headquarters Marine Corps
IDFW	International Data Farming Workshop
IED	Improvised Explosive Device
INP	Innovative Naval Prototype
JOA	Joint Operations Area
JIC	Joint Integrating Concept
LCAC	Landing Craft Air Cushion
LCS	Littoral Combat Ship
LCU	Landing Craft Utility
M&S	Modeling and Simulation
MAGTF	Marine Air Ground Task Force
MANA	Map Aware Non-uniform Automata
MCCDC	Marine Corps Combat Development Command
MEB	Marine Expeditionary Brigade
MOE	Measure of Effectiveness

MPF(F)	Maritime Prepositioning Force (Future)
NOLH	Nearly Orthogonal Latin Hypercube
NDS	National Defense Strategy
NPS	Naval Postgraduate School
OMFTS	Operational Maneuver From The Sea
ONR	Office of Naval Research
ROMO	Range of Military Operations
SASO	Stability and Security Operations
SEED	Simulation Experiments and Efficient Design
SES	Surface Effect Ship
SSG	Surface Strike Groups
SSTR	Stability Security Transition and Reconstruction
STOM	Ship To Objective Maneuver
SW	Surface Warfare
TTP	Tactics, Techniques, and Procedures
T-Craft	Transformable Craft
WMD	Weapons of Mass Destruction
XML	eXtensible Markup Language

ACKNOWLEDGMENTS

First and foremost I want to thank God for providing me with the strength, endurance, and patience necessary to complete this project. I am also thankful that He blessed me with a loving wife, Tara, and two wonderful daughters, Kamara, and Heighley. I could not have asked for a better family and am eternally grateful for their unwavering support.

I would also like to thank my advisor, Dr. Gary Horne, my second reader, Dr. Tom Lucas, my research assistant and combat modeling expert, Mary McDonald, and my consultant, Colonel Ed Lesnowicz, USMC (retired), for their guidance and for helping me keep this research relevant. I would also like to thank Capt Jeff Kline USN (Ret), for the guidance and the operational experience he shared with me.

Finally, I would like to thank the professors and staff of the OR department. Their professionalism and dedication is unsurpassed.

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Seabasing is the future of joint operations abroad. However, without sufficient supporting craft, the seabase concept will be ineffective in accelerating the deployment of forces and sustainment ashore. To that end, in August of 2005, the Office of Naval Research (ONR) issued Broad Agency Announcement (BAA) 05-020 with the intent of developing an innovative naval prototype (INP) that would have a "game changing" impact on seabasing. Specifically, this BAA is focused on the seabase connector Transformable Craft (T-Craft). The purpose of the INP program's T-Craft concept is to establish a ship that is capable of performing the arduous chore of transferring cargo at sea in sea states well above the current operating threshold of sea state 2.

This innovative basing plan eliminates the need to control hostile ports or airfields. It also allows greater flexibility when operating in countries that do not have the necessary infrastructure at ports or airfields for conducting military operations. The seabasing concept expands upon the concepts of Operational Maneuver from the Sea (OMFTS) and Ship to Objective Maneuver (STOM), where storming a heavily defended beachhead is no longer the objective. All of these initiatives move the maneuver area into the ocean, giving combatant commanders the capability to maneuver combat elements under the concealment of the horizon.

This research provides the Office of Naval Research and the U.S. Marine Corps with analytical support for operational performance requirements, which will hopefully aide in design determinations and influence concept of operations and employment methods. This thesis is guided by two questions:

- Does the T-Craft need an organic self-defense capability?
- How should the T-Craft be employed when a threat exists?

These questions are addressed using simulation, data farming techniques, and data analysis. In addition to providing insight into these questions, this thesis provides a foundation for the use of simulation and data farming techniques for follow-on studies of

this project or related topics. The intent of this thesis is to provide analytic support to determine the best configuration of an employed T-Craft in order to complete a mission conducted in a region where complex threats exist.

In order to accurately address the questions driving this research, two previously developed scenarios are used in this thesis. These scenarios were developed in other studies pertaining to the T-Craft and focus mainly on the concept of logistic support and sustainment for ongoing operations. For the purpose of this thesis, those same scenarios, slightly modified, are used to assess the threat environment and develop some suggestions on how to properly protect the T-Craft as it conducts its mission. The first scenario is a peacekeeping and peace enforcement operation that takes place in Colombia, South America. The second scenario takes place in Malaysia, where a regional conflict has developed. In both of these scenarios, the T-Craft is conducting follow-on sustainment operations in an environment where multiple threats exist. Along with the threat, escorts and weapons are varied in each scenario to see how the changes affect T-Craft survivability and throughput.

This thesis uses an agent-based distillation, which is a type of computer simulation that attempts to capture the critical factors of interest in combat without explicitly modeling all of the physical details. A low resolution, agent-based simulation tool is used to simulate a set of approved scenarios for the T-Craft. Map Aware Non-Uniform Automata (MANA), developed by New Zealand's Defense Technology Agency (DTA), is used to implement the scenarios. This research uses a technique called data farming, which produces large numbers of data points through the use of high performance computing. This process allows numerous variables (i.e., number of T-Craft, numbers of LCSs, number of patrol boats, and probabilities of kill for weapon systems) to be analyzed over broad ranges, providing insight into a large number of possible outcomes. Through this technique over 430,000 T-Craft missions were simulated, 205,200 of which are used to produce the research data. These simulated operations were conducted in little time, and would have been time consuming and costly if conducted in real life. Figure S1 shows a snapshot of both the Colombia and Malaysia scenarios.

Figure S1. MANA screen shot of both scenarios.

Each question is addressed and explored through data analysis. As a result of the analysis, additional insights were gained. The additional findings are one of the main characteristics of data farming. So much information was varied and run through the models that in looking for one data point, several more nuggets of information were discovered. This information proved to be useful and relevant, especially in understanding the significance of shoreline threats of semi-submersibles and swarm craft, and the relationship between the T-Craft and speed. The analysis of the questions provided the following model generated insights:

- Organic weapons increase the survivability of the T-Craft.
- If escorts aren’t present, the T-Craft should utilize the tactics, techniques, and procedures (TTP) of return to the seabase when a threat is present.
- The presence of escorts significantly improves the survivability of the T-Craft and the number of T-Craft ashore.
- The T-Craft being armed and having escorts present improves the T-Craft survival rate and number of T-Craft ashore.
- When a threat is present, T-Craft speed has a negative correlation with survivability. As speed increases, survivability decreases. Thus, the T-Craft should not travel faster than the escorts.
- A security gap was discovered along the shoreline. In both scenarios the enemy threat along the shoreline has a significant effect on both T-Craft survivability and the number of T-Craft ashore.
- Improving the sensors and communication links on the T-Craft will improve the survivability of the T-Craft.
- The LCS needs to stay with the T-Craft rather than pursue distant enemies.

Upon completion of the simulation experiments and data analysis, the results of this study support the following recommendation for the two scenarios modeled:

- The T-Craft should have an organic weapons system.
- The recommended T-Craft and escort mix for the scenario with a surface and subsurface threat is 10 T-Craft, two LCS_SW, three LCS_ASW, and five MH-60s.
- The recommended escort mix for the scenario with a pure surface threat is seven T-Craft, two LCS_SW, one LCS_ASW, and five MH-60s.
- The recommended T-Craft speed is dependent on the escorts being used; for these scenarios the recommended range is between 20 and 30 knots.

This thesis provides analytic support for arming the T-Craft and gives insights into a mix of escorts based on the region and threat. The end product is information that can be used by decision-makers in developing policies, concepts of operations (CONOPS), and tactics, techniques, and procedures (TTPs).

I. INTRODUCTION

A. OVERVIEW

1. The Office of Naval Research Broad Agency Announcement

Over the last several years, U.S. armed forces have conducted combat operations in Iraq and Afghanistan, brought humanitarian aid and relief to hundreds of thousands affected by the earthquake in Haiti, and evacuated American citizens from Lebanon in the largest non-combatant evacuation since the fall of Vietnam (Conway, 2006). As a joint force, the Army, Navy, Marine Corps, and Air Force continually work to shape and prepare current and future force structures in order to meet projected threats. To that end, in August 2005, the Office of Naval Research (ONR) issued a Broad Agency Announcement (BAA) 05-020 with the intent of developing an innovative naval prototype (INP) that would have a “game changing” impact on seabasing. Specifically, this BAA is focused on the seabase connector Transformable Craft (T-Craft) prototype demonstrator. The purpose of the INP program’s T-Craft concept is to establish that a ship is capable of performing the difficult task of transferring cargo at sea in sea states well above the current operating threshold of sea state 2. In addition, this ship will demonstrate the ability to transform into an amphibious vessel capable of delivering cargo feet-dry above the high water mark of a beach (Wilson, 2005).

2. Seabasing Defined

Seabasing is defined as the rapid deployment, assembly, command, projection, reconstitution, and re-employment of joint combat power from the sea (DoD, 2005). In addition, the seabase has the capability to provide continuous support, sustainment, and force projection to joint expeditionary forces without reliance on land bases or ports. The seabase is in essence a maneuverable, scalable aggregation of distributed networked platforms that enables the global power projection of offensive and defensive forces from the sea (CNO, 2006). Figure 1 shows the principles of seabasing.

Principles of Seabasing

1. Use the sea as a maneuver space.
2. Leverage forward presence and joint interdependence.
3. Project joint force operations.
4. Provide scalable, responsive joint power projection.
5. Sustain joint force operations from the sea.
6. Expand access options and reduce dependence on land bases.
7. Create uncertainty for our adversaries.

Figure 1. The principles of seabasing. (From DoD, 2005)

Under this concept, the ideal base of operations will be established between 150 and 200 nautical miles (nm) off the coast of a Joint Operations Area (JOA) (CNO, 2006). The seabase may consist of several different ship configurations based on the type of operation being conducted, the requests of the joint force commander, or the availability of assets within the region of conflict. The seabase may include some of the following: Carrier Strike Group (CSG), Amphibious Ready Groups (ARG), Expeditionary Strike Group (ESG), Littoral Combat Ships (LCS), Surface Strike Groups (SSG), combat logistics forces, amphibious forces, Army afloat program ships, coalition forces, and maritime prepositioning ships (CNO, 2006). The ultimate goal of the seabase is to tactically and logistically support a brigade-size (or larger) unit ashore. Currently this capability does not exist. Figure 2 depicts the envisioned make-up of the seabase.

Figure 2. Depiction of the seabase concept with the airfield afloat and port facilities afloat. The seabase can be as small as three vessels or as large as required for mission accomplishment. (From Doyle, 2008)

This innovative basing plan eliminates the need to control hostile ports or airfields. It also allows greater flexibility when operating in countries that do not have the necessary infrastructure at ports or airfields for conducting military operations. The seabasing concept expands upon the concepts of Operational Maneuver from the Sea (OMFTS) and Ship to Objective Maneuver (STOM), where the days of storming a heavily defended beachhead are no longer the objective. All of these initiatives move the maneuver area into the ocean, giving combatant commanders the capability to maneuver combat elements under the concealment of the horizon (MCCDC, 1996). Seabasing also reduces force protection challenges ashore, especially during early stages of a crisis. Gone are the days of landing on a heavily defended beach and creating a large footprint once ashore. Combatant commanders now have at their disposal an advanced expeditionary and amphibious capability that gives them the flexibility to focus on entry points where the enemy is most vulnerable or is absent. This gives the commander an advantage over the enemy force (CNO, 2006).

3. The Seabase Connector Transformable Craft

In order to bring forces to bear on the enemy from the seabase, a seabase connector is required. Numerous studies concluded that an effective seabase operation must have more capable connector craft than currently available (Conway, 2006; CNO, 05; CNO, 06; MCCDC, 96; MCCDC, 1997). The current inventory of seabase connectors in place consists of medium and heavy lift aircraft, landing craft air cushion (LCAC), and landing craft utility (LCU). There are several problems with the current inventory of seabase connectors. These limitations include the limited cargo capacity of aircraft and the LCAC, the slow travel speed of the LCU, and the inability of the LCAC and LCU to operate in sea states higher than 2. Under the BAA, a prototype will be designed to overcome these shortfalls (Helland, Rowden, & Jimenez, 2009).

The transformable craft is the proposed prototype that will bridge the gap between operational speed, lift capability, operability in sea states up to sea state 4, and landing on unimproved beaches. The T-Craft will also enable the conduct of the full range of military operations (ROMO) from the sea. Requirements for the T-Craft include the

ability to deploy from an initial staging base unloaded to the seabase with an unrefueled range of 2500 nm miles. Once at the seabase, the T-Craft must be able to withstand wave-induced motions in sea states between 4 and 5 while interfacing with either Navy amphibious ships or commercial logistics ships allowing for the rapid transfer of materiel. The transfer is followed by high-speed transit of 40 knots to the surf zone with an unrefueled range of 500 nm. Finally, the T-Craft will transform into amphibious mode and traverse sand bars carrying its load well above the high-water mark, thereby reducing the chance of vehicles getting stuck in loose sand. In essence, the T-Craft will perform the role of heavy lift surface effect ship (SES) and transition to amphibious air cushioned vehicle (ACV) while carrying the same load (Anderson & Triola, 2009).

B. BACKGROUND AND MOTIVATION

The ending of the Cold War brought about the initial impetus for the seabasing concept development. For almost two decades, the U.S. Navy and Marine Corps have been actively engaged in producing a robust and comprehensive body of seabasing concepts and supporting Concepts of Operations (CONOPS). In recent years, this body of work has expanded to include the joint community and has been formalized into naval doctrine (MCCDC, 2009). In the early 1990s, several white papers were published that addressed this change in premise of naval operations. The 1991 white paper *The Way Ahead* addressed the concept of a new pattern of deployments and force composition to maintain the forward presence required to support the full ROMO. *From the Sea* was published in 1992; it postulates the need for expeditionary operations that focus on the littorals and joint force enabling (MCCDC, 2009). *Operational Maneuver From the Sea,* published in 1996, served as the capstone of a series of operating concepts on naval operations. In essence,

> OMFTS is an amphibious operation that seeks to use the sea as an avenue for maneuvering against some operational-level objective, pitting strength against weakness. It is a concept for projecting maritime power ashore. The concept recognizes the requirements for forcible entry—an amphibious landing in the face of organized military resistance—although not all operational maneuvers from the sea entail forcible.

Between 2002 and 2004, the office of the Secretary of Defense issued guidance to increase strategic speed for two almost-simultaneous major combat operations. The guidance drove further development of optimizing the ability of projecting combat power from the sea. This discussion led to the development of the Marine Expeditionary Brigade (MEB) and the Maritime Prepositioning Force (Future) (MPF(F)) as the primary means of carrying out this mission (RAND, 2007). *Maritime Prepositioning Force (Future)* described the ways in which maritime prepositioning, although it had been effective during recent operations, needed to evolve in order to fully support OMFTS and future operations. In this paper, the call was made for new technologies to be pursued and developed in order to permit the next generation to contribute to operational employments across the full range of operations, and thus to include the rapid reinforcement of forward deployed amphibious forces (MCCDC, 2009).

"Naval Power 21" articulated a unified naval vision, and emphasized the utility of naval forces across a range of operations. It also highlighted the importance of seabasing for projecting "power, defense, and influence" (MCCDC, 2009). "Naval Transformation Roadmap 2003" and "Sea Power 21" were published in 2003. "Naval Transformation Roadmap" stated, "seabasing [as] a national capability, is our overarching transformational operating concept," describing it as the global power projection of offensive and defensive forces from the sea to execute combat operations ashore (MCCDC, 2009). "Sea Power 21" documented the Navy's operational vision for the 21st century. This vision developed the fundamental premise to help joint force commanders accelerate deployment and employment of naval power and to enhance seaborne positioning assets. "Sea Power 21" goes on to explain that this will be accomplished by minimizing logistics stockpiles ashore, which in turn will reduce the operational demand for sealift and airlift assets, ultimately permitting the forward positioning of joint forces for immediate employment (RAND, 2007).

Finally, in 2005, "Seabasing Joint Integration Concept" (JIC) was published. This document leveraged all of the concepts developed during the period from the early 1990s to 2005 and put all services on the same road map for strategic development. The "Seabasing JIC" describes how combinations of forces that are forward deployed and

prepositioned could provide strategic speed, access, and persistence for a range of military operations. It outlines these key concepts of seabasing: closing, assembling, employing, sustaining, and reconstituting joint forces from a seabase. It also defines its relevance to strategic guidance and joint concepts, lays out assumptions and risks, identifies essential capabilities, defines attributes, and provides guidelines of how joint seabasing can be executed to support national military objectives (DoD, 2005). Along with the document, the "Seabasing JIC" was amplified by four detailed, illustrative CONOPS set in the 2015 to 2025 timeframe.

In March 2005, "National Defense Strategy" (NDS) emphasized the importance of influencing events before challenges became more dangerous and less manageable. It explained that the U.S. faced a time of uncertainty and that it needed to address an array of current and future adversaries. These adversaries were suspected of employing traditional, irregular, and weapons of mass destruction against the U.S. (DoD, 2005; MCCDC, 2005; MCCDC, 2009). It identified the need to enhance eight key operational capabilities, most of which made the case for seabase operations. In his speech to the graduating class of the U.S. Naval Academy in 2005, President Bush said, "We are developing joint sea bases that will allow our forces to strike from floating platforms close to the action, instead of being dependent on land bases far from the fight" (DoD, 2005). The current National Security Strategy, National Defense Strategy, and National Military Strategy all emphasize the need for military access to retain global freedom of action (MCCDC, 2009). They postulate that future security environments will become increasingly complicated due to international political relationships, increased acts of terrorism, the expanded influence of non-state actors, and the proliferation of weapons of mass destruction (WMD). Potential enemies are more likely to attack U.S. forces abroad with increasingly lethal weapons, including WMD. Clearly, the need for military access to retain global freedom of action has been a consistent theme over the last two decades. The seabasing concept conforms to this strategic initiative and is an extension of the goal of assuring allies and friends, deterring aggression and enemies, dissuading potential adversaries, rapidly responding to irregular, catastrophic and disruptive challenges, and if necessary, quickly defeating foes in combat (DoD, 2005).

With the solidification of the seabasing concept, the next step was to modernize seabase connectors. As stated earlier in this chapter, the current inventory of seabase connectors cannot stand up to the robust demands of the new concept of operations. This brought about BAA 05-020, which was one of three initiatives to enhance seabase operations.

C. RESEARCH QUESTIONS

The goal of this thesis is to simulate T-Craft operations in a JOA and analyze its performance with respect to survivability in a hostile environment. This was done by the modeling and simulation of two scenarios. The first is a peacekeeping and peace enforcement scenario and the next is a regional conflict scenario. These simulations were run in order to address the following questions:

- Does the T-Craft need an organic self-defense capability?
- How should the T-Craft be employed when a threat exists?

In addressing these questions, data farming allows for the understanding of an enormous landscape of possibilities, along with the advantages to this new technology and with the short falls.

D. BENEFITS OF THE STUDY

This research will provide the following stakeholders—the U.S. Navy, the U.S. Marine Corps, the Office of Naval Research and contract developers—with an understanding of operational performance requirements, which will hopefully aide in design determinations and influence concept of operations and employment methods. Through modeling and simulation (M&S) the objectives include addressing, and possibly validating, some of the T-Craft requirements given in the BAA: determining critical factors and threshold values, assessing sensitivities, evaluating performance across a spectrum of conflict conditions, and generating distributions on future possibilities.

E. METHODOLOGY

This thesis uses an agent-based distillation, which is a type of computer simulation that attempts to capture the critical factors of interest in combat without explicitly modeling all of the physical details. A low resolution, agent-based simulation tool is used to simulate a set of approved scenarios for the T-Craft. Map Aware Non-Uniform Automata (MANA), developed by New Zealand's Defense Technology Agency (DTA), is the tool used to model T-Craft operations in an environment where an enemy threat is present (Anderson, Galligan, Lauren, & McIntosh, 2007).

Through the use of MANA, a robust design of experiment, and data farming, this thesis develops a means by which ONR can evaluate design configurations of the T-Craft and make an informed decision on how the T-Craft should be protected while engaged in operations that cover the full ROMO. Quantifiable measures of effectiveness for both mission areas covered by this thesis are identified and used to determine a concept of employment. Design of experiment techniques are used to vary the speed, the force size, and the probabilities of detection and kill for each agent developed. Once the baseline model was developed, further high dimensional experiments were used to explore the performance of the T-Craft in threat situations. Exploratory analysis, or data farming, identified previously undetermined characteristics and situations that became apparent during the simulation runs (Cioppa, Lucas, & Sanchez, 2004). Statistical analysis and other analytical analysis techniques identified and determined the importance of interactions between variables and led to a better understanding of the significance of the data. The results of the analysis will help identify possible alternative methods of employing the T-Craft, which could contribute to mission success.

F. THESIS ORGANIZATION

Chapter II begins with a more detailed description of the T-Craft and the scenarios that are used to test the T-Craft's performance. The chapter closes with a detailed description of the simulation model created for this thesis and an overview of the modeling tool MANA. Chapter III offers a discussion of the design of experiments that are used for this analysis and includes a description of the variables used in the analysis

phase, as well as an explanation of Nearly Orthogonal Latin Hypercubes (NOLHs). Chapter IV gives a description of the analytical methods used to interpret the results of the simulated tests and concludes with an explanation of the analytical results. Chapter V completes the thesis with a discussion of the insights gleaned from the analysis and recommendations for follow-on research.

THIS PAGE INTENTIONALLY LEFT BLANK

II. MODEL DEVELOPMENT

A. INTRODUCTION

Seabasing is the future of joint operations abroad. However, without sufficient numbers of supporting craft, the seabase concept will be ineffective in the ability to accelerate the deployment of forces and sustainment ashore. An ineffective seabase would then limit rather than enhance the joint force commanders' flexibility in conducting operations (National Defense Research Institute, 2007). The purpose of the INP initiated by ONR was to develop all of the technology required to ensure the success of seabasing and OMFTS. Nevertheless, the T-Craft is the conduit to mission success. For that reason, the T-Craft's operation parameters will need to be meticulously tested. Some of those tests were replicated in this thesis through robust modeling and simulation (M&S). The scenarios developed in this thesis address two of the five potential mission packages that the T-Craft is expected to perform. Included in these scenarios are enemy threats that the T-Craft may encounter while operating. The concept paper, "Ship-To-Objective Maneuver," states that

> [h]ostile combined arms forces supported by integrated air and coastal defense systems remain the greatest threat to landing forces[...] the enemy may attempt to defeat or disrupt the amphibious force by contesting control of the air, surface, or subsurface battle space. He may attack the force at sea, attempt to repel the landing force during the assault phase, counter attack on land to eject the landing for, or any combination of the above. (MCCDC, 1997)

It is imperative that critical vulnerabilities and design recommendations be identified in the design and development stage rather than after full-rate production of the T-Craft begins. In this chapter, an introduction and description of the T-Craft is presented, followed by a brief definition of the range of military operations (ROMO) that the T-Craft is expected to perform, along with a description of the scenarios used in this thesis. Finally, the agent-based model MANA and the model's behavior are discussed.

B. WHAT IS THE TRANSFORMABLE CRAFT?

1. Overview

The Transformable Craft, or T-Craft, was briefly described in Chapter I; this chapter provides a more detailed look. "Game-changing" performance is the defining concept of the T-Craft. It will be bigger, faster, and more durable than any other seabase connector in the Navy's current inventory. The need for this innovative technology is a result of moving the seabase from the current 8 to 15 nm off the coast to 150 to 200 nm off the coast. By design, ONR identified a list of operational capabilities the T-Craft should posses. Figure 3 lists the prescribed operational capabilities and Table 1 lists the desired operating thresholds of the T-Craft as published in the BAA.

Capability List:

1. Un-refueled range, in a no cargo condition, of 2,500 nautical miles in a Fuel Efficient / Good Sea Keeping Mode (20 knots, through Sea State 5).
2. Open ocean operations through Sea State 6 (through Sea State 4 in High Speed/Shallow Water Mode) and Survivable in Sea State 8.
3. Maximum Speed, full load condition in High Speed, Shallow Water Mode = ~40 knots through top end of Sea State 4.
4. Amphibious capability, in Amphibious Mode, to traverse sand bars and mud flats thereby providing a "feet dry on the beach" capability.
5. Ability to convert between modes at-sea without any external assistance.
6. Maximum un-refueled range in High Speed / Shallow Water Mode = ~500-600 nautical miles (40 knots, through Sea State 4).
7. Ability to mitigate wave-induced motions in Sea State 4/5 to enable rapid vehicle transfer (loading /un-loading) between the T-CRAFT and a Maritime Prepositioning Force (Future) / Sealift Ship.
8. To be used as an assault connector and a logistics connector

Figure 3. Transformable craft capability list. (From ONR, 2005)

Thresholds/objectives:

Notional Requirements	Threshold	Objective
Cargo Payload	300 lt	750 lt
Cargo Payload Area	2,200 sqft	5,500 sqft
Crew Size	3	2
Beach Slope Climbing	0.5%	2%
Vehicle Ramp Angle	15.0 degrees	12.5
Vehicle Deck Loading	350 psf	550 psf

Table 1. Transformable craft thresholds and objectives. (From ONR, 2005)

The LCAC is the current high-speed seabase connector in use by the Navy today. It is capable of operating from amphibious deck ships of the ARG and is fully amphibious. Although it has been said that the T-Craft is not, and will not be developed as a replacement for the LCAC, the LCAC is used as a reference to give an appreciation of the new technology being developed. The LCAC’s cargo area is 1809 square feet and it can lift up to 75 long tons. Its top speed is listed as 40 knots and it can travel up to 200 nm with payload at 40 knots, or 300 nm with payload at 35 knots, without refueling. The LCAC can transport only one M1A1 tank and primarily operates in sea state 2 or below (Global Security.org, 2006a). From these numbers, one can see that the T-Craft will have more than twice the cargo space and potentially up to ten times the LCAC’s lift capability. In addition, the T-Craft is being designed as a surface effect ship with the capability of transforming into an amphibious ship. This allows the T-Craft to deploy from an initial staging base under its own power and increases its flexibility of use. In light of the capabilities previously listed, there are some other design considerations that have been specifically left out. These items are listed in Figure 4.

Other relevant Information:

1. No habitability / living space required.
2. Prototype will not be classified, however potential follow-on craft may be required to be classified.
3. No requirement to fit into Navy Amphibious Ship Well Decks (L-Class ships).
4. On board fire-fighting capability should be automated to the maximum extent possible to meet the desired crew size.
5. No stealth or signatures requirement.
6. No organic capabilities required to handle pallets, quad-cons, or 20 ft containers.

Figure 4. Capabilities not required to be built in to the T-Craft. (From ONR, 2005)

2. Seaframe

When ONR published the BAA, three design proposals were approved. The three corporations currently developing prototypes for this program are Alion, Textron, and Umoe Mandal. Figures 5, 6, and 7 show design sketches of each prototype being developed.

Figure 5. The Alion Transformable Craft prototype is built on a catamaran-type frame. (From Chang, 2008)

Each design will have the challenges of meeting the specified capabilities prescribed by ONR. Some of these challenges include developing technology that is large enough to self-deploy over long distances in a high sea state while at the same time maintaining fuel efficiency. This will be achieved by using a catamaran frame (Alion) or high-ratio mono-hulls (Textron and Umoe); this SES cushion design provides low wetted area for high-speed powering and motion control.

Figure 6. The Textron Transformable Craft prototype closely resembles the LCAC, which Textron also designed; both have an open cargo area. (From Chang, 2008)

The stability provided by the frame design facilitates steady cargo transfer at the seabase in high sea states. As the fully loaded T-Craft nears the shore, it then transforms

into an amphibious vehicle in order to traverse sand bars and land securely on the beach. The designed ACV and skirt system enables amphibious operations. This transformation process reverses itself once the T-Craft transitions back to a SES for its return to the seabase for follow-on operations (Wilson, 2009).

In addition to the hull design, the engine and structural material also play a role in the game-changing performance of the T-Craft. The power plant boasts a multi-mode propulsion system that increases the T-Craft's range and that provides fuel-efficient high-speed open ocean transit. It also provides the power needed for high-speed transit between the seabase and shore along with amphibious propulsion. Aluminum, titanium, and composites are being tested as potential hull and structural materials (Dale, 2010).

Figure 7. The Umoe Transformable Craft prototype has a high-speed surface effect hull design with closed cargo area. (From Chang, 2008)

Ramp technologies and dynamic positioning systems are necessary to accomplish material transfer at the sea base in high sea states, and advances in automation and human systems integration are required in order for the T-Craft to be operated by a minimal two- to three-man crew. Table 2 shows some of the T-Craft's design specifications.

Ballast Conditions - T-Craft Model No. 5687			
Scale Ratio = 30.209			
Parameter	Model Scale as tested	Equivalent Full Scale as tested	
	Inches	feet	meters
Length Overall	99.5	250.48	76.35
Length Waterline off cushion	98	246.71	75.20
Length Waterline on cushion	88	221.53	67.52
Draft (on cushion)	1.73	4.36	1.33
Draft (50% cushion)	3.15	7.94	2.42
Draft (off cushion)	5.2	13.19	4.02
Draft (barge condition)	0.87	2.18	0.66
Beam Max	29	73.01	22.25
Cushion Width	21.5	54.12	16.50
Cushion Length	87.5	220.27	67.14
Displacement (fresh water model scale lbs; salt water full scale Ltons/tonnes)	121.5	1533.67	1558.6
LCG (forward from wet deck transom)	48.49	122.07	37.21
TCG (starboard of centerline)	0	0.00	0.00
VCG (below deck)	0.25	0.63	0.19
Pitch gyradius	28.32	70.88	21.6
Roll gyradius	10.44	26.28	8.01

Table 2. Prototype design specifications. (Dale, 2010)

In essence, the T-Craft is three vessels in one (SES, Transport Ship Vessel, and ACV) and must be fully operational in each mode without assistance from outside equipment. Contractors are currently in the process of designing their innovative systems in anticipation of presenting them to ONR.

3. Mission Framework

As a joint force asset, the T-Craft will be used across the full ROMO. Joint Publication 3-0, “Joint Operations,” details a list of military activities employed across the ROMO (DoD, 2005). Figure 8 shows the range and types of military operations that the T-Craft will support.

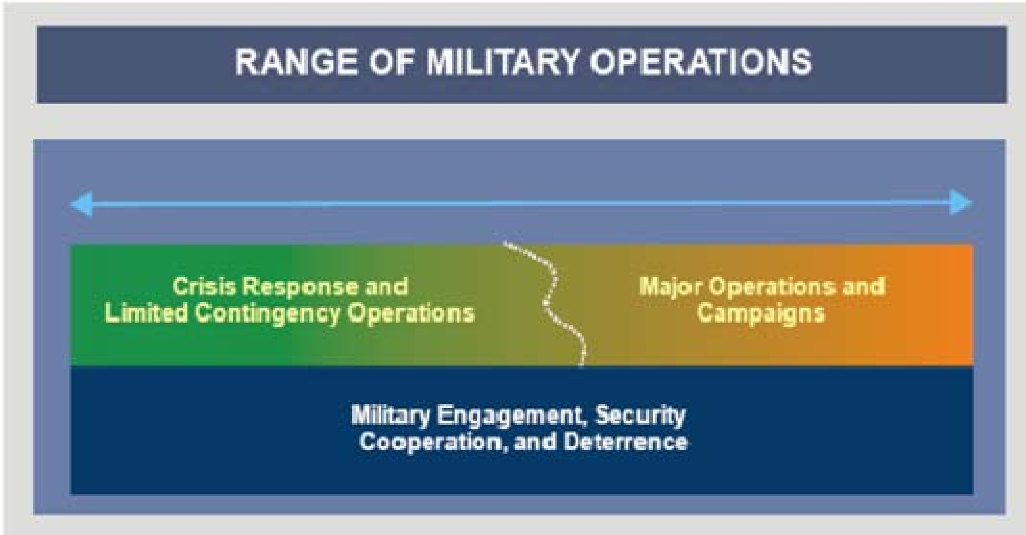


Figure 8. Range of military operations. (From Anderson, et al., 2009c)

For the purposes of the T-Craft program, it is possible to categorize the ROMO and types of military operations into an abstract framework that illustrates the high-level operational contexts in which future T-Craft assets could be deployed and employed. Table 3 lists the recommended categories of military operations for consideration.

Figure 9. Types of military operations. (From Anderson, et al., 2009c)

The framework attempts to align mission groupings based on two primary considerations. The first is operational scale; and the second is number and type of

resources typically deployed. In all, the 20 military operation types listed in Figure 9 occur through five operational categories. Table 3 lists operational categories, which provides additional context and structure for further assessment for the T-Craft.

• Routine Forward Presence Operations • Campaign Operations: Global Surge / Force Concentration • Long-Duration SASO / SSTR Operations • Limited Duration, Limited Objective Operations

Table 3. Recommended T-Craft operational categories. (From Anderson, et al., 2009c)

One of the systems that have not been mentioned thus far is the armament system. This fact is because the initial designs do not require weapon systems. As with most military vehicles designed to support combat operations, it would be typical to see the design or mention of some form of weapon system or countermeasures to be a part of the development. However, that is not the case with the T-Craft. If the T-Craft is going to serve to deliver forces and sustainment for a combat operation such as forced entry against a determined adversary, the T-Craft must be designed to function in the combat environment (Anderson, et al., 2009c). The key here is that the T-Craft must be able to survive in a hostile environment. It is important to mention that this thesis is not preconditioned to suggest the T-Craft needs a weapon. On the contrary, the intent is to develop a recommendation based on thorough analysis of various aspects of potential environments that the T-Craft may encounter, and of the Navy's available assets to protect the T-Craft.

C. DESCRIPTION OF SCENARIOS

The scenarios used in this thesis were developed in other studies related to the T-Craft. Those scenarios focused mainly on the concept of logistic support and sustainment for on-going operations. In this thesis, those same scenarios, slightly modified, are used to assess the threat environment and to develop some suggestions as to how to properly protect the T-Craft as it conducts its mission. The first scenario is a peacekeeping and peace enforcement operation in Colombia, South America. The second scenario takes place in Malaysia, where a regional conflict has developed.

It is important to note at this point that the “Arc of Instability” is an area of interconnected and politically unstable nation states in the Asia-Pacific region. The term originated in the early 1990s and is used to suggest that if one nation located in an interconnected chain is destabilized, major political, military, and economic repercussions will occur in neighboring countries (MCCDC, 1996). This situation could in turn result in external interdiction from other nations or organizations, namely the United Nations or the United States. Figure 10 shows the interconnected regions that are known as the “Arc of Instability.” While this is not an official classification, it is highlighted for planning guidance and strategy for future operations. As can be seen in Figure 10, this region consists of coastal countries, making it substantially a maritime domain; therefore, a naval force is uniquely suited to respond (Conway, 2006; DoD, 2005).

Figure 10. The “Arc of Instability” as described by the Pentagon for future conflicts and military presence. (From Doyle, 2008)

While the scenarios used in this thesis are realistic and depict potential future threats and operations, the enemy threat was never taken into account. A full description of both scenarios can be found in Appendix A. The situations described below are tactical excerpts based on the region and type of operations.

1. Peacekeeping and Peace Enforcement

The year is 2025, and the Colombian Civil War has raged in the country for 60 years. The Colombian people appear to have lost confidence in the democratic process. The economy is suffering from the worst crisis the country has ever seen. During the previous two years, guerrillas and the San José Cartel have executed thousands of public officials and are responsible for the killing of more than 17,000 people in 420 massacres (Helland, Jimenez, & Rowden, 2009; Helland, Paulo, & Rowden, 2008).

The San José cartel has established an alliance with the Colombian insurgency movement, specifically the Revolutionary Armed Forces of Columbia (RAFC). This aforementioned relationship later sparked the creation of the Common Front of the Liberation of Colombia (CFLC), which later became the security force for the San José cartel. From 2023 to 2025, the CFLC was able to cripple the Colombian armed forces, including the Air Force and Navy. They were able to do this through coordinated attacks and support from the insurgency (Helland, et al., 2009; Helland, et al., 2008).

a. Enemy

Through coordinated attacks, the CFLC seized 37 of 41 Naval vessels from Colombian bases. This seizure was confirmed when a merchant vessel sank after striking a mine 37 miles northwest of Buenaventura (Helland, et al., 2009). In addition to the surface threat, the CFLC has also reportedly converted its semi-submersible technology from drug trafficking to carrying explosives, presumably in order to defend the Colombian coast from any form of intervention. It has also been confirmed that Venezuela has provided patrol craft and weapons to the CFLC and Colombian cartels.

b. Friendly

The United Nations (U.N.) Security Counsel has held several meetings on the instability in the region. The United States has sought a resolution calling for a U.N. peacekeeping force to restore the failed government, and eliminate the CFLC and other cartels. After seeing the resolution vetoed, the U.S. decided to unilaterally insert forces into Colombia that are capable of destroying the cartels, resisting Venezuelan influence,

and ultimately restoring a democratic government (Helland, et al., 2009). For the purpose of this thesis, the 2nd MEB embarked on two Amphibious Ready Groups are the forces that will be inserted.

The MEB will be inserted on the southern Colombian coast near the coastal town of Tumaco. The seabase will be established 50 nm of the coast of Colombia. The initial assault echelon will land under cover of darkness while the T-Craft will transport the follow on assault elements and sustainment required to conduct operations.

Included in the seabase are two ARGs carrying the MEB, an MPF(F) squadron, and a section of littoral combat ships. The LPDs will provide the capability to conduct air operations from the sea base. The other ships in the ARG will perform the traditional duties of debarking Marines and craft to shore. The MPF(F) will provided sustainment for operations ashore. The T-Craft will be the primary seabase connector for follow-on assault waves and sustainment. The total number of T-Craft in this scenario will vary. Finally, the section of littoral combat ships contains a mix of surface warfare-configured ships and antisubmarine warfare configured ships. The primary mission of the LCSs is to escort the T-Craft to and from shore, immobilizing any threat that appears along the way. Organic to the littoral combat ship, and used in this scenario, is the MH-60R. The primary mission of the MH-60R is to provide early detection and eliminate enemy threats, if capable. This portion of the operation should take no more than 24 hours to conduct.

c. Mission

The mission of the T-Craft is to provide the uninterrupted build-up of combat power ashore. The mission of the LCSs is to clear the sea-lanes of enemy forces in order to allow the safe transit of the T-Craft to shore. Figure 11 is a screen shot of the simulated scenario.

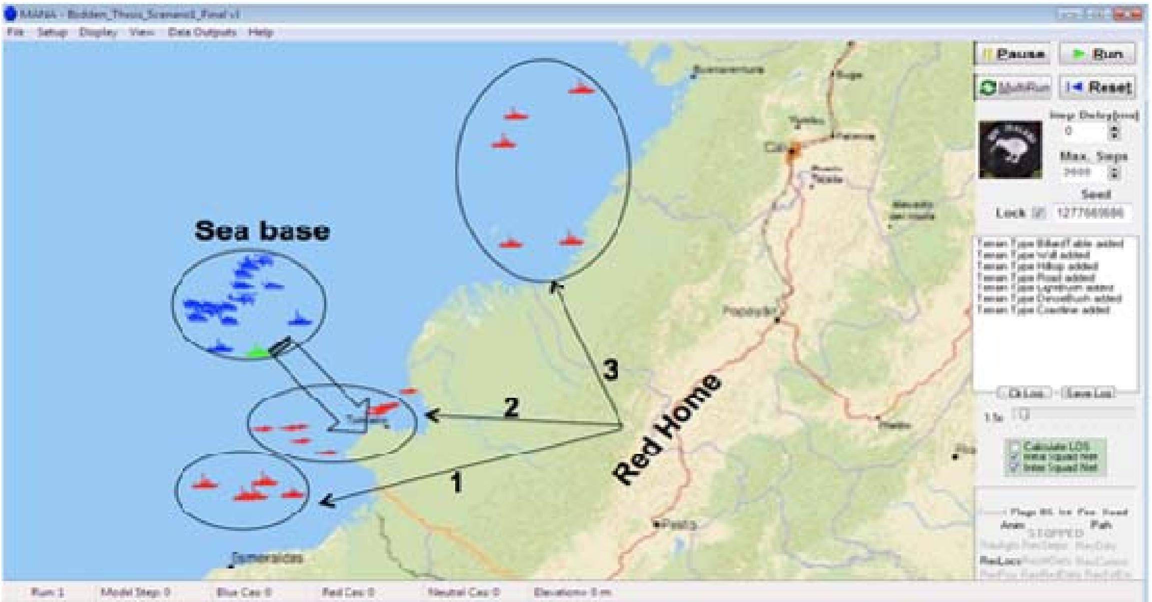


Figure 11. Screen shot of Colombia scenario at problem start. The sea base contains the T-Craft, LCS SW and ASW, MH-60, and Destroyers. Red Home 1 and 3 contain patrol boats. Red Home 2 contains semi-submersibles.

2. Regional conflict

The Kalimantan (KA) Republic became an independent nation in October 2002, when General Gegwan Riady proclaimed that the four Indonesian provinces on Borneo were seceding from Indonesia to create a new republic. In the year 2025, the KA Republic suffered a reversal in its economic fortunes due to the collapse of the world petroleum market and a revelation of overestimated offshore energy resources. As a result of this new economic position, Riady sought financial aid from their neighbors to the North, Malaysia, and Brunei. But, with Kalimantan's debt in the billions, neither neighbor was willing to offer financial support. Outraged, Riady sought to correct the economic inequality between North and South, developing the mantra "One Borneo, One Nation." This slogan later became the central focus of the KA military planning (Helland, et al., 2009; Helland, et al., 2008).

a. Enemy

The KA Government called on the Malaysian separatists movement to help KA in the coming fight for economic equality. Two Kalimantan army divisions

began using air and amphibious forces to gain footholds in Malaysia. The First Kalimantan Division (KD) landed near Kuching and began driving west through Malaysian territory. The Third KD moved into Sandakan on the east coast of Malaysia, and began driving west towards Brunei. Reportedly, KA naval forces laid sea mines in the Trusan Strait, effectively blocking Malaysian and Brunei naval forces (Helland, et al., 2009; Helland, et al., 2008).

It is believed that KA forces will use their naval patrol craft to launch attacks on forces attempting to land along the Malaysian coast. The KA will further use swarm tactics on soft targets in order to disrupt operations to thwart their operations.

b. Friendly

The U.S. will reinforce Malaysian units in order to deter further KA expedition and to conduct combat operations should deterrence fail. The 1st MEB will support forces near Bintulu. The threat of sea mines will prevent the use of major shore points of debarkation until mine countermeasure assets can clear the restricted waterways (Helland, et al., 2009). Thus, forces will arrive via T-Craft to beachheads near friendly forces. The seabase will consist of two MPF(F) squadrons collocated to reduce naval security requirements. The seabase will also consist of two LCS detachments configured with surface and antisubmarine warfare packages.

c. Mission

The mission of the T-Craft is to provide the uninterrupted build-up of combat power ashore. The mission of the LCSs is to clear the sea-lanes of enemy forces in order to allow the safe transit of the T-Craft to shore. Figure 12 is a screen shot of the modeled scenario.

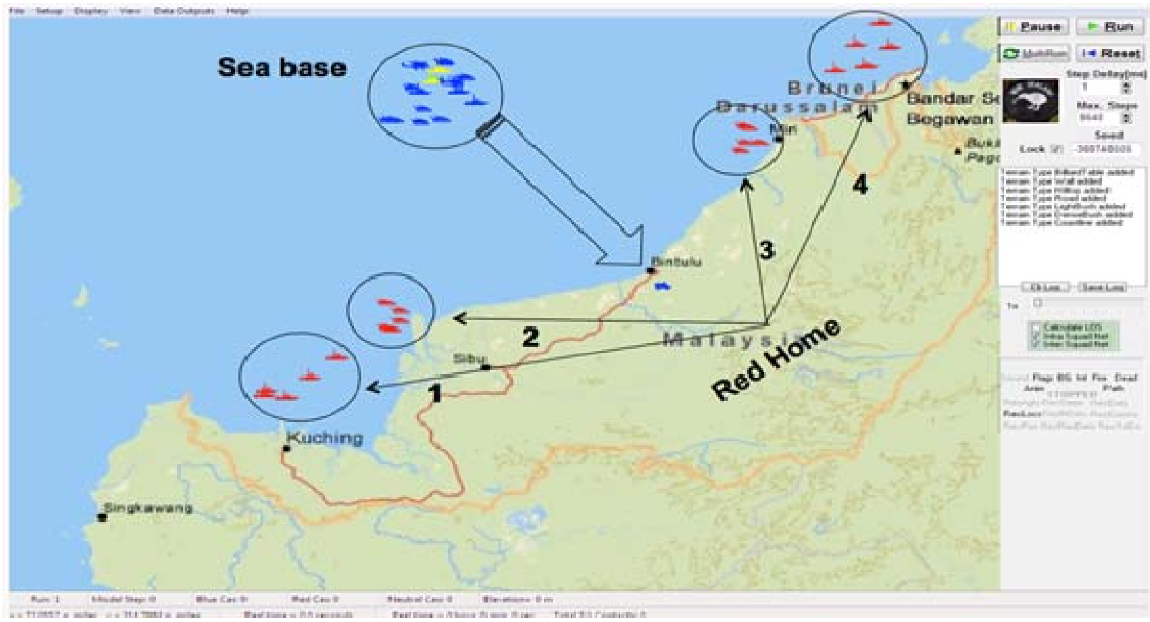


Figure 12. Screen shot Malaysia scenario at problem start. The sea base contains the T-Craft, LCS SW and ASW, MH-60, and Destroyers. Red Home 1 and 4 contain patrol boats. Red Home 2 and 3 contain swarm boats.

D. THE AGENT-BASED MODEL MANA

With the details of the scenario described, the tool used to model the scenarios will now be introduced. The introduction of the modeling environment is followed by an overview of how the scenarios are implemented in the model.

1. What is MANA?

Map Aware Non-Uniform Automata (MANA) is an agent-based distillation model. It was designed by the New Zealand DTA for use as a scenario-exploring model, and is intended to address a broad range of problems. MANA was developed as a result of the frustrations in analyzing the output of physics-based models.

> While these [physics-based] models purport to be detailed […] it becomes clear immediately once one starts to attempt to analyze the value of various aspects such as situational awareness, command and control, and the informational edge that enhanced sensors provide, that physics based models are quite limited. (Anderson, et al., 2007)

Physics-based models tend to predetermine the behavioral outcomes of agents and do not take into account abnormal or random behavior. DTA took the shortcomings of

physics-based models into account and developed MANA to compensate for the behavioral activities of entities in the combat model (Anderson, et al., 2007).

MANA is based on two key components. The first is that the behavior of entities within a combat model is a critical component of the analysis of the model's possible outcomes. Second, time may be used ineffectively when using highly detailed physics-based models for determining force mixes and combat effectiveness (Anderson, et al., 2007). These aforementioned components were the main influence in making MANA version 5 the model of choice in this thesis. Other factors that influenced the decision to use MANA include flexibility, relative ease of use, and the ability to run large experiments in a relatively short time period. The MANA model allows the easy incorporation of terrain and elevation, communications, and numerous pre-programmed state changes. In MANA, one can quickly build a rough skeleton of the model from a realistic scenario, and then refine agent parameters and state changes to create a reasonably accurate model of the combat interactions desired. The flexibility of the model allows simple changes to be made in order to conduct experiments and what-if analysis. In this research, a MANA model was constructed iteratively through the use of the scenario and research into the agent attributes and properties. Once the base case was constructed, it was simple to create numerous variations to fully explore the questions posed by this research.

Figure 13. Screen shot of MANA version 5 "about" screen with contact information.

2. Characteristics of MANA

MANA builds on and complements the earlier ISAAC-EINSTein Cellular Automaton (CA) models developed by the Center for Naval Analyses. It was designed to explore key concepts that ISAAC was unable to explore at the time (Anderson, et al., 2007). Specifically, MANA was able to capture:

- Situational Awareness: A collective group memory of perceived enemy contacts. This is done through the use of situational awareness maps. MANA has two: squad map and inorganic map. The squad map provides direct information through squad contacts and the inorganic map provides information through communication links. Agents have situational awareness of the other agents and terrain that is updated by sensors and communications.
- Communications: Allows communication of contact sightings between squads. The communications feature can be explored through several parameters and characteristics in MANA. Individual agents may have different behavior parameters, capabilities, sensors, weapons, and communications.
- Terrain Map: This contains terrain features much like a regular chart or map. Terrain can be developed in such a realistic way that agents can travel on roads or seek cover behind structures built into the model. Terrain features can be built into any scenario in such a way to accurately depict what the modeler is trying to model.
- Waypoints: Agents within MANA can travel to multiple objectives, they are not limited to just one path or goal.
- Event-driven personality changes: Agents are developed to react independently on the battlefield according to their own individual characteristics. To aid the user in creating a more realistic behavior, there are a multitude of default event triggers available in MANA. Each trigger allows you to create agent behavior based on the action or trigger. Some of the triggers available in MANA are: reach waypoints, out of ammo, being shot at, enemy contact, squad death, and out of fuel to name only a few. Personality changes can be for an individual or an entire squad (Anderson, et al., 2007).

The MANA modeling environment is user-friendly and is quick to understand. It has well-developed Graphical User Interface (GUI) and contains data farming features that provide the ability to explore an extensive range of input parameter settings in minimal time.

E. CHARACTERISTICS OF THE SIMULATION MODEL

1. Goal

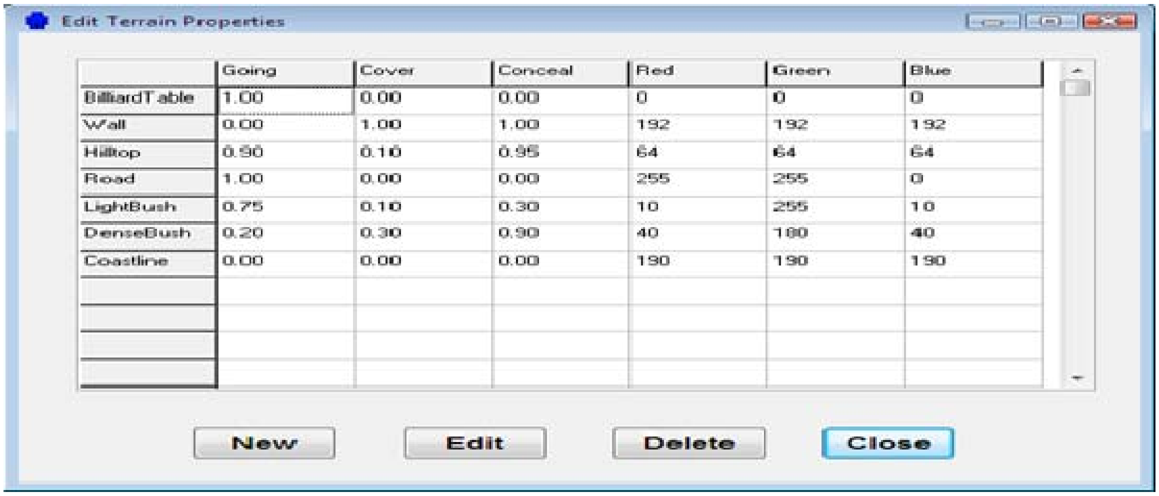
The scenarios developed for this study were designed to gain insight into the significance of arming or escorting the T-Craft when there is a threat, as opposed to conducting operations unarmed and unescorted in the same hostile environment. The primary measure of effectiveness (MOE) is mean T-Craft Survival Rate and the secondary MOE is mean Number of T-Craft Ashore. Some of the factors varied in this simulation are the number of T-Craft, the number and type of LCSs, the number of MH-60s, the number of Destroyers and the number of enemy craft.

2. Terrain and Scale

Because MANA is a time step model, there must be a mapping from real time to simulation time, and from real space to simulation space. In the implementation of this scenario, one model time step is equal to ten seconds of real time. Each scenario lasts no longer than 8640 time steps, which equals 24 hours. The simulation map consists of 1760 pixels by 1272 pixels, corresponding to a real world map of 440 nm by 318 nm. This produces a pixel to nautical mile ratio of about 4:1, which provides good detail for accurate modeling of agent movements. Each pixel is thus approximately 1/4 of a nautical mile, or 463 meters. Although this scenario takes place at sea and force-on-force engagements generally take place over a large distance, the use of a larger pixel to nautical mile ratio would create unrealistic agent movements. The above combination translates into a single simulation run that lasts approximately two to three minutes on a modern laptop processor. The time variation is a result of the number agents being used in a run.

MANA was originally developed to model land warfare; however, MANA does have the capability to create sea-based and other type scenarios. Default terrains such as hilltop, light or heavy brush, roads, and walls give way to islands and water. Because the scenarios for this research are all nautical, the only terrain used is a customized coastline feature that prevents ships and semi-submersibles from running aground. A terrain map was created by selecting the desired area map, and then using the MANA Scenario Map

Editor to line the coastline in the map with the coastline feature. The agents are able to use situational awareness features to navigate along the terrain. Different terrain features are assigned different colors in MANA: gray with a red, green, and blue (RGB) of 190 is the color for the coastline feature. Figure 14 shows the edit terrain properties screen through which the coastline feature was created.



	Going	Cover	Conceal	Red	Green	Blue
BilliardTable	1.00	0.00	0.00	0	0	0
Wall	0.00	1.00	1.00	192	192	192
Hilltop	0.90	0.10	0.95	64	64	64
Road	1.00	0.00	0.00	255	255	0
LightBush	0.75	0.10	0.30	10	255	10
DenseBush	0.20	0.30	0.90	40	180	40
Coastline	0.00	0.00	0.00	190	190	190

Figure 14. Screen shot of Edit Terrain Properties.

The terrain map is not seen by the user while conducting runs; rather, what is seen is the background map. This allows the user to display a recognizable, real-world map during simulations without affecting the agent's simulation awareness. Essentially, the terrain map is for the agents and the background map is for the user. Figure 15 shows the terrain and background maps for the Colombia scenario.

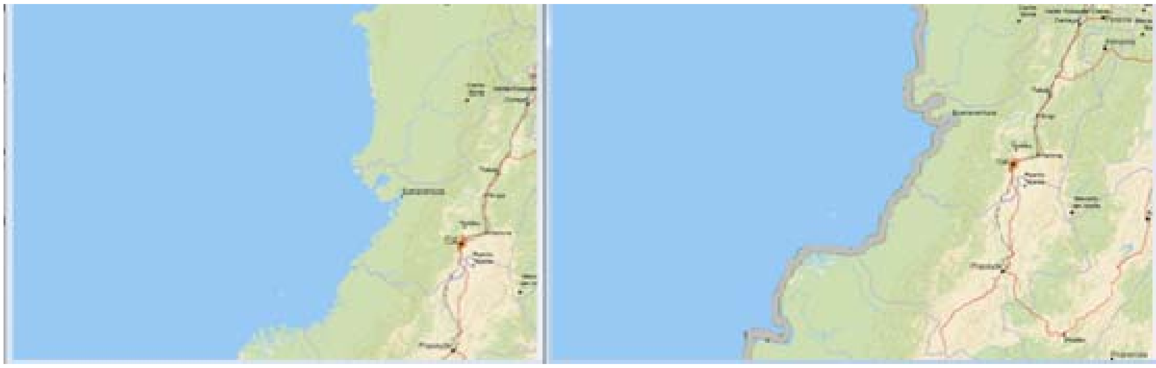


Figure 15. Background (left) and Terrain (right) maps used in the Colombia scenario. The gray lining along the terrain map is the coastline feature. The Malaysia scenario was painted in the same manner.

3. Enemy Forces

Each enemy agent is assigned a home location. In both scenarios, in an attempt to vary enemy threat activity, enemy agents are set to have random start times, i.e., with each iteration of the model, the order in which enemy agents appear on the game board is random. The patrol boats will patrol the coast until they detect friendly forces, and the patrol route is set by a series of waypoints along the coastline. The primary target of the patrol boat is the T-Craft because it is not armed or is only lightly armed. The secondary targets for the patrol boats are the LCSs. If a patrol boat comes in contact with either of the aforementioned targets, it will increase speed and attack those targets. If faced with both targets at the same time, the personality is set to go for the T-Craft.

In the Colombia scenario, semi-submersibles "patrol" in the home position along the coastline where friendly forces previously landed, and are expected to land. The semi-submersibles are remote-guided and are very hard to detect. They will continue to float until destroyed by friendly force fire or detonating on friendly craft.

Finally, the swarm tactic is a threat relevant in the Malaysia scenario. Swarm boats patrol very close to the coastline until they detect friendly forces; the patrol route is set by a series of waypoints along the coastline. The swarm boats, like patrol boats, have the primary target of the T-Craft. However, unlike patrol boats, swarm boats stay away from the LCSs once detected. If an LCS is detected, a swarm boat will try to evade the threat. When the swarm boats come in contact with the T-Craft, the designed behavior is to group all boats together (swarm) and attack the T-Craft.

4. Friendly Forces

Each friendly agent is assigned a home location that also represents the seabase. In addition, friendly agents are assigned waypoints that will direct them from the seabase to the shore base, and back. The only friendly agent that is stationary is the destroyer. In both scenarios, the destroyer stays at the seabase and provides oversight for sustainment operations. The T-Craft transits from the seabase to the shore, avoiding enemy patrol boat and swarm threats. When the T-Craft detects a semi-submersible, the T-Craft attempts to slow down in order to maneuver around it or destroys it with its onboard weapon system, if armed.

The LCSs patrol the waters between the seabase and the shore base. They are formed in such a way to provide a lane through which the T-Craft can transit. Once an enemy is detected, the LCSs engage the enemy and return to their escort mission. Organic to both the LCS and destroyer are the MH-60. In each scenario, the MH-60 flies a search pattern in order to detect and engage any enemy threat. The refueling of the MH-60 is simulated through the rearming of the helicopter. Once out of hellfire missiles, the MH-60 will return to the seabase to rearm and refuel, which takes an hour.

5. Data Sources, Abstractions, and Assumptions

In order to better understand the simulation model, it is important to know the source of input data and assumptions made in the modeling effort. In this simulation, communications and logistics are assumed to work perfectly, i.e., regarding logistics, the location and number of available mission packages is not considered, and fuel (with the exception of helicopters) is unlimited. Failure of equipment and maintenance are also not considered in this simulation.

Enemy force sensor and weapon information, number of weapons per enemy agent, and capabilities of certain friendly sensors and weapons were taken from *Jane's Fighting Ships 2006*, *The Naval Institute Guide to Combat Fleets of the World (15th ed.)*, and the Global Security Web site. The values given to enemy sensors and weapons were generalized and reviewed by subject matter experts.

Enemy and friendly weapon systems posed another modeling challenge. Since there are friendly aircraft in each scenario, weapons had to be programmed to deal with this threat. However, those weapons that would not normally fire at air targets had to be adjusted. Also, in the Colombia scenario, due to the angle of fire, not all weapons could be used to engage the semi-submersibles. Thus, in order to compensate for both issues, the advanced weapon feature was used. Under the weapons tabs, weapons systems were modified so that the weapon would only engage class-specific targets in order to obtain the needed realism in each scenario.

In the Colombia scenario, the sensor classification and detection range for the semi-submersible was very different from that of the patrol boats and swarm boats. To

deal with these differences, friendly forces were assigned two separate sensor types. The sensor classification range and the detection ranges were much smaller for the semi-submersibles than for the boats. The advanced sensor was used to create a near-, mid-, and far-range detection rate with varying classification probabilities. Designing the sensor in this manner added to the realism of how difficult it would be to detect the semi-submersible in the water.

In these scenarios, sea-based assets performed integrated force protection. These forces included surface combatants, submarines, aircraft, and air and missile defenses, as well as assets organic to forces assembling at sea (DoD, 2005). Due to the significant firepower located at the seabase, the threat of the seabase being attacked was not addressed. It was assumed that the U.S. forces had air superiority in both scenarios and that there was no deep-water sub-surface threat in either scenario.

With both of these scenarios some assumptions were made. The first is that the MPF(F) squadron would be ready for use, functioning with the designed capabilities. The MPF(F) squadron, still in the developmental stage, was regarded as a major step forward in Marine Air Ground Task Force (MAGTF) operations. Unlike the current maritime prepositioning ship squadrons, which are densely packed, require safe usable ports, and take several days to prepare to unload, the MPF(F) will have the capability to sustain a brigade size element from the 14 ships of the squadron (RAND, 2007). Furthermore, these scenarios do not specifically address the positioning and ability of the T-Craft to dock with the future supply ships. The estimated times to dock, load, transport to shore, and return to the seabase, which were gleaned from previous studies, were used to account for the time of T-Craft operations.

As stated earlier in this chapter, there is no design requirement for the T-Craft to have a weapon system. After further research and discussion with subject matter experts, the recommendation was made to model the T-Craft with an MK110 57mm weapon system and a 30mm cannon weapon system. Weight and space requirements were the rationale behind this decision. The MK110 is upgraded from the previous design MK3 57mm; it is currently the secondary weapon on the LCS surface warfare package and the primary weapon system on the LCS anti-submarine warfare package. This new

technology represents the biggest weapon system the T-Craft would carry without compromising space. The 30mm cannon is a much smaller weapon system, but the effectiveness of the weapon makes it very efficient to use as a defense weapon system. Further, this model does not include the UAVs organic to the LCS_ASW package.

During the model generation phase, the model was reviewed frequently by simulation experts and analysts to ensure the agent behaviors were adequately modeled. The model benefited from input from military officers, analysts, and simulation experts at NPS and from those affiliated with NPS, although located elsewhere. This feedback was used to produce accurate scenarios that would produce quality results.

6. Summary

This research uses the MANA simulation tool to model a realistic combat environment where the T-Craft will be employed. The scenarios cover specific aspects of the threat environment the T-Craft will encounter, with the intent of gaining insights as to how the T-Craft should be employed. The result is a simulation that captured the inherent dangers of operating in hostile territory and identified potential capabilities for enhancing the survivability of the T-Craft. The following chapter contains a description of the variables of interest followed by a description of the experiment design.

III. EXPERIMENTAL DESIGN

A. INTRODUCTION

Data farming is the process of using high performance computers or computing grids to run a simulation thousands of times, while simultaneously varying input parameters across a large parameter and value space. As a result of data farming, an enormous amount of output data is provided that can be analyzed for trends, anomalies, and insights (Cioppa, Lucas, & Sanchez, 2004). In this thesis, data farming techniques are used to gain insights into T-Craft performance in an operational environment. To ensure that the simulation model was searched efficiently, an experimental design was necessary. The design in this thesis was developed through the use of state-of-the-art Nearly Orthogonal Latin Hypercubes (NOLHs). By using NOLH, it was possible to thoroughly explore the design space, further enhancing the ability to explore simulation outputs (Cioppa, Lucas, & Sanchez, 2004). In this chapter, the modeling variables of interest are discussed followed by a description of the designs used in this thesis. The chapter closes with an explanation of how the experiment was run.

B. VARIABLES OF INTEREST

Two types of variables are commonly used in simulation: controllable and uncontrollable. Controllable variables are those that can be altered by a decision maker in the real world; uncontrollable variables are those that a decision maker cannot control. Controllable variables are referred to as decision factors, while uncontrollable variables are considered noise factors. This thesis focuses on decision factors in order to provide greater insight into how T-Craft should be deployed when a threat is present. Because the enemy and their attributes are considered noise factors, the only variable characteristics in the designs are the number of red agents present. Modeling details for each agent and their sensors and weapons is provided in Appendix B. Table 4 summarizes the variables used, their ranges, and a brief description.

Table 4. Variable factors used in experimental design. Decision factors are in blue print and noise factors are in red print.

Factor	Value Range	Description
T-Craft	**5 – 11**	**Number of T-Craft in a given design**
Speed in knots	**20 – 55**	**Speed of the T-Craft in a given design**
Active Weapon	**1, 2, 3 (both)**	**Weapon that is activated during a given design**
LCS_SW	**1 – 10**	**Number of Surface Warfare configured LCSs in a given design**
LCS_ASW	**1 – 5**	**Number of Anti-Submarine Warfare configured LCSs in a given design**
MH – 60	**1 – 10**	**Number of MH – 60s in a given design**
Destroyers	**1 – 3**	**Number of Destroyers in a given design**
Mk110 57mm Pk	**0.5 – 1**	**Probability of kill by 57mm**
30mm Cannon Pk	**0.5 – 1**	**Probability of kill by 30mm**
Red Patrol Boats	**0 – 10**	**Number of Red Patrol Boats in a given design**
Semi-submersible	**0 – 5**	**Number of Semi-submersibles in a given design**
Swarm	**0 – 15**	**Number of Swarm boats in a given design**

1. Controllable Factors

The following factors were selected with the intent of obtaining the best insights into how the T-Craft should be equipped in a hostile environment.

a. T-Craft

The number of T-Craft available at the seabase in a given design. The number varied from 5 to 11 in each scenario.

b. Speed

The speed at which the T-Craft traveled in a given design. The speed of the T-Craft varied from 20 to 55 knots in the full design and from 35 to 55 knots in preliminary designs.

c. Active Weapon

The active weapon in a given design. The range varied from one to three in the full model. Each number represents a weapon configuration.

- 1 represents the Mk110 57mm weapon system
- 2 represents the 30mm cannon weapon system
- 3 represents both weapons being active in a design

d. LCS_SW

The number of LCS_SW assigned to the seabase to conduct the escort mission for a given design. Since both scenarios represent primarily a surface threat, the max number of LCSs in each scenario is 30.

e. LCS_ASW

The number of LCS_ASW assigned to the seabase to conduct the escort mission for a given design. The maximum number of LCS_ASW in each scenario is five.

f. MH - 60

The number of MH – 60s attached to the seabase. The number of MH - 60 helicopters varied from one to ten in both scenarios.

g. Destroyer

The number of destroyers attached to the seabase. The number of destroyers varied from one to three in both scenarios.

h. MK110 57mm Pk

The probability of kill (Pk) associated with the MK110 57mm weapon system used by the T-Craft seaframe. This variable is modeled in both scenarios.

i. 30mm Cannon Pk

The probability of kill associated with the 30mm cannon weapon system used by the T-Craft seaframe. This variable is modeled in both scenarios.

2. Uncontrollable Factors

The following uncontrollable variables were chosen in order to ensure the scenarios were realistically uncertain and to explore the capabilities of the T-Craft and escort variations defined by the number of LCSs, MH-60s, and destroyers over a range of conditions. These variables are factors that a decision maker would be unable to effect and are thus seen as noise factors.

a. Patrol Boats

The number of patrol boats used in a given run. The number of patrol boats varied from zero to ten in both scenarios, due to their role as the primary threat. The patrol boats in the Colombia scenario are modeled on the Venezuelan Navanita class patrol craft. The patrol boats in the Malaysia scenario are modeled on the French PR-72 560 class patrol combatant ship (PGG).

b. Semi-submersibles

The number of semi-submersibles used in a given run. They varied from zero to five in the Colombia scenario, where they served as a secondary threat.

c. Swarm Boats

The number of swarm boats used in a given run. The number of swarm boats varied from 5 to 15 in the Malaysia scenario, due to their role as the secondary threat. The swarm boats are modeled after the Filipino FELIX APOLINARIO patrol boat.

C. THE EXPERIMENT

1. The Nearly Orthogonal Latin Hypercube (NOLH)

The NOLH is a space-filling experimental design technique developed in 2002 by Colonel Thomas Cioppa, United States Army, at the Naval Postgraduate School (NPS). This technique allows for the exploration of a large number of input parameters in an efficient number of runs, while maintaining nearly orthogonal design columns (Cioppa, 2002). The space-filling property of the NOLH allows the analyst to explore more of the input space than the traditional factorial design, in which only high and low values are considered. Figure 16 shows the space-filling properties of the NOLH design.

Correlations

	Num T-Craft	Active Weapon	T-Craft Speed	# LCS_SW	# LCS_ASW	MH-60	MK 110 57mm Pk	30mm Pk	Destroyers	Red Patroll Boat	Semi-submersible
Num T-Craft	1.0000	-0.0122	-0.0029	-0.0010	-0.0006	-0.0028	0.0043	0.0054	0.0394	-0.0130	-0.0173
Active Weapon	-0.0122	1.0000	0.0190	-0.0197	0.0111	-0.0145	0.0181	-0.0083	-0.0465	0.0037	-0.0494
T-Craft Speed	-0.0029	0.0190	1.0000	0.0036	-0.0095	-0.0079	-0.0030	-0.0001	-0.0130	0.0112	0.0073
# LCS_SW	-0.0010	-0.0197	0.0036	1.0000	0.0108	-0.0013	-0.0010	-0.0054	-0.0021	0.0003	-0.0131
# LCS_ASW	-0.0006	0.0111	-0.0095	0.0108	1.0000	-0.0252	-0.0090	0.0013	0.0022	-0.0130	0.0010
MH-60	-0.0028	-0.0145	-0.0079	-0.0013	-0.0252	1.0000	-0.0036	-0.0056	-0.0457	0.0136	-0.0018
MK 110 57mm Pk	0.0043	0.0181	-0.0030	-0.0010	-0.0090	-0.0036	1.0000	0.0000	-0.0013	-0.0073	0.0134
30mm Pk	0.0054	-0.0083	-0.0001	-0.0054	0.0013	-0.0056	0.0000	1.0000	-0.0384	-0.0109	-0.0101
Destroyers	0.0394	-0.0465	-0.0130	-0.0021	0.0022	-0.0457	-0.0013	-0.0384	1.0000	0.0347	-0.0165
Red Patroll Boat	-0.0130	0.0037	0.0112	0.0003	-0.0130	0.0136	-0.0073	-0.0109	0.0347	1.0000	-0.0040
Semi-submersible	-0.0173	-0.0494	0.0073	-0.0131	0.0010	-0.0018	0.0134	-0.0101	-0.0165	-0.0040	1.0000

The correlations are estimated by REML method.

Scatterplot Matrix

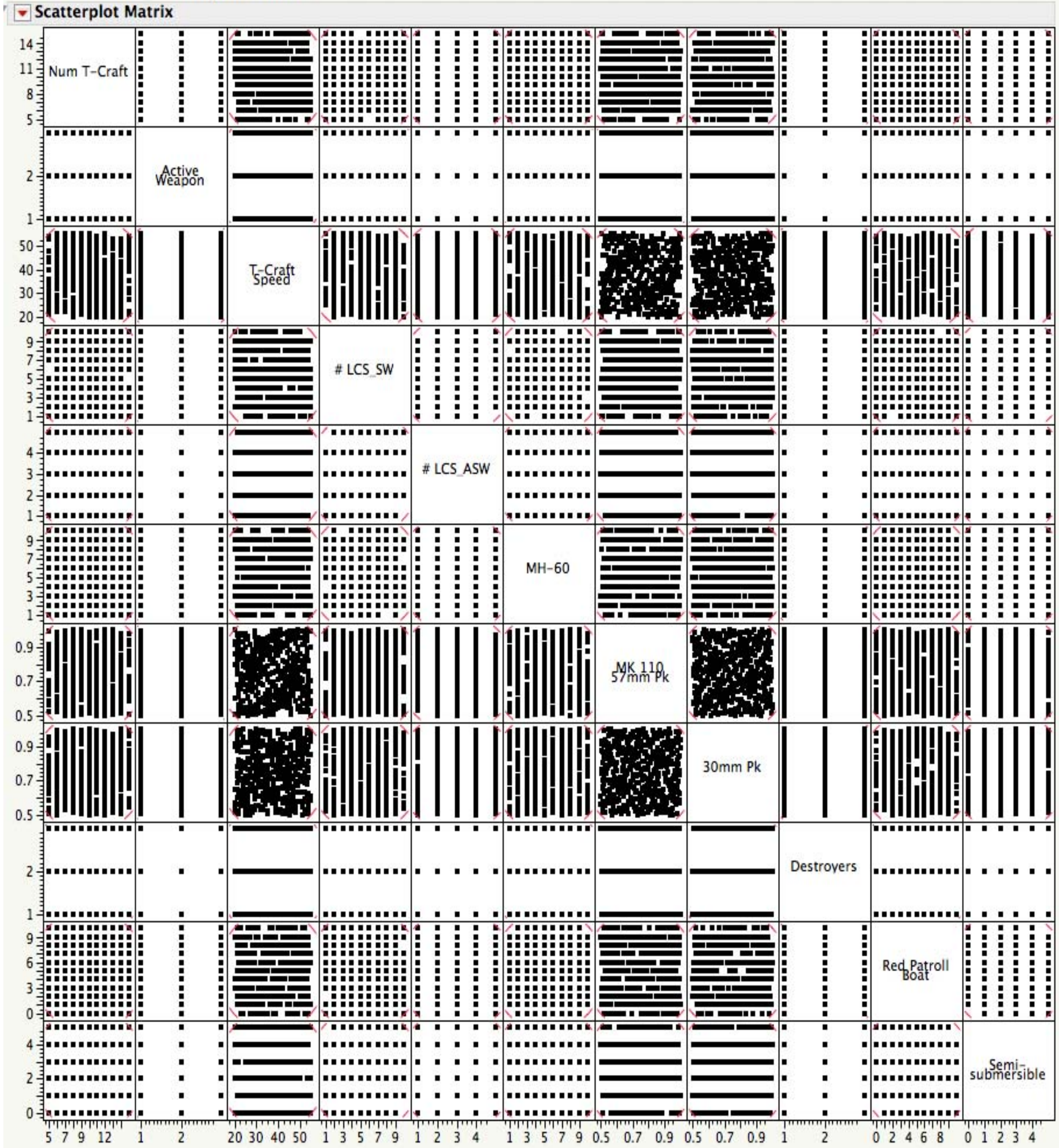


Figure 16. Correlation matrix and scatter plot of the full design Colombia scenarios that illustrates near orthogonality and the space filling properties of the NOLH.

2. Exploratory Model Design

In order to evaluate the realism of the modeled scenario, an exploratory design was developed. This design used a NOLH design that consisted of 18 factors and 129 design points. Simple rounding was used for discrete variables. Each design point was replicated 50 times, generating a total of 6,450 simulated missions. In the design, the numbers of friendly and enemy vessels were varied, along with the probability of kill for each of the friendly weapon systems, and the friendly sensor detection ranges. The measure of effectiveness (MOE) for this run was the mean T-Craft Survival Rate. Had the NOLH not been used, in order to conduct a full factorial exploratory run with the same 18 factors at only 2 levels, the simulation would have needed to be run 2^{18} times for a total of 262,144 replications; each run takes a little over a minute and thus it would have taken over 182 processor days to run that design. Analysis of the exploratory runs showed a negative correlation with sensor ranges, meaning that the detection of enemy at farther distances increased the number of T-Craft kills. As a result, it was determined that the behavior of the LCSs was very aggressive in pursuing enemy vessels, leaving the T-Craft vulnerable to counter attacks. As a result of these experiments, adjustments were made to friendly agent behavior. Appendix C contains all of the NOLH designs used in this thesis.

3. Preliminary Model Design

Once adjustments were made to the model, a preliminary design was developed to further explore the simulation. The preliminary design was created to provide a more detailed look at each scenario after the refinement from the exploratory design. This design consisted of 11 factors and 257 design points. Each design point was replicated 50 times using the same MOE as before; mean T-Craft Survival Rate. These data points were analyzed and the results reviewed during the International Data Farming Workshop 20 (IDFW 20) by simulation experts, analysts, and military officers to ensure that the scenarios were being modeled correctly before conducting the full experiment. Some of the adjustments made from these preliminary results include: increasing the number of

LCS_SW and MH-60 in both scenarios, adjusting the probability of kill rates of the T-Craft weapons using the mid range value as the base, and tracking the MOE mean Number of T-Craft Ashore.

4. Full Model Design

After further refinement to the simulation model based on the inputs from the previous designs, the full design was implemented. The full model design consisted of two stages. The first stage was developed in order to explore the question of T-Craft configuration with respect to having a weapon or not, and having escorts or not. The second stage of the design was set up to determine the best employment method of the T-Craft. The stage one design consisted of eight factors and 513 design points created by the NOLH. Each run was replicated 100 times, resulting in 51,300 data points per scenario. The stage two design consisted of 11 factors, and 513 design points created by the NOLH. Each of these runs was replicated 100 times, resulting in 51,300 data points per scenario as well. These data points were used as the research data for this thesis.

D. RUNNING THE EXPERIMENT

MANA uses eXtensible Markup Language (XML) files to run simulations. After identifying the input variables and creating the runs through the NOLH, an XML file had to be created for each run. The subsequent XML files were then placed on a cluster of computers operated by the Simulation Experiments and Efficient Design (SEED) Center for Data Farming at NPS. This cluster of high performance computers conducted the simulations for all of the designs. Chapter IV discusses the output from the full design and the data analysis conducted to gain insights into answering the questions posed in Chapter I.

IV. DATA ANALYSIS

The methodology described in the previous chapter resulted in a large amount of data. This chapter begins with an explanation of how the data was compiled and prepared for analysis. The purpose of the analysis was to provide insights into the research questions outlined in Chapter I. Next, the data from each scenario is presented and analyzed followed by a discussion of the analysis. The chapter concludes with additional insights gleaned from this study.

A. DATA COLLECTION AND PROCESSING

The simulation output provided by MANA is given in the form of a comma-separated values (CSV) file that allows for simple handling. In addition to NOLH design inputs, the simulation output also provided the number of injuries for each agent, along with the number of casualties for each agent identified by the squad number in each scenario. Additional columns were added to the output file in order to track the T-Craft survival rate and number of T-Craft ashore. The scenario output file contains the results of all 100 replications of each run, resulting in 51,300 rows of data. The Statistical package JMP version 8 was used to compile and analyze all of the output data provided by the simulation run (*JMP Statistical Discovery Software, Version 8.0.1*, 2009). Using JMP, the average of each input combination was taken, resulting in 513 rows of mean values. Included in this new data set were the MOEs used for this experiment: mean T-Craft Survival Rate and mean Number of T-Craft Ashore. The mean T-Craft Survival Rate tracks the ratio between the number of T-Craft at the start of the simulation against the number of T-Craft at the end of the simulation run. Mean Number of T-Craft Ashore tracks the number of T-Craft landings on shore. The same process was used to set up the data used in the second stage design, which results in 513 rows of mean values.

B. INSIGHTS INTO RESEARCH QUESTIONS

In Chapter I, two questions were presented as the basis of this research. Those two questions are restated in paragraphs that follow. Each question is addressed and explored through data analysis. In an attempt to be as thorough as possible, analysis was conducted

using several analytical and statistical tools. Regression models and prediction plots are a few of the tools that are used and discussed in this chapter. The chapter closes with insights gained as a result of this analysis.

Regression analysis is used to identify significant factors that contribute to the desired MOE. The R-squared or adjusted R-squared values are examined to assess the adequacy of the model developed through regression analysis. R-squared is a statistic that measures the proportion of the variability in the MOE explained by the fitted model. A high R-squared indicates a close match between the fitted model and the MOE. A major concern with using R-squared is that there is no penalty for adding variables to the model. R-squared will increase as variables are added, whether the added variable is significant or not. However, the adjusted R-squared does not always increase as a result of simply adding variables to the model. The adjusted R-squared will only increase if the addition of the variable to the model reduces the residual mean square. The reduction in error often signifies that that variable is important and should be in the model (Montgomery, Peck, & Vining, 2006). The adjusted R-squared is the statistic that is used when assessing a regression model in this research.

The prediction plot is part of the regression output provided by the software package JMP8. The plots show the significant variables identified by the developed model. Each plot can be adjusted to see how the adjustment affects the predicted response. This tool is very useful in highlighting the relationships between the main effects in the fitted model (JMP8, 2009).

1. Does the Transformable Craft Need an Organic Weapon System?

This section addresses the survivability of the T-Craft. Factors such as having weapons or not, having escorts or not, and using prescribed tactics, techniques, and procedures (TTP) or not in a threat environment are explored for each scenario. The default escort mix (Escort[1]) is five LCS_SW, two LCS_ASW, and four MH-60s. The variable Return to Seabase is the TTP and defines the action of the T-Craft when enemy

patrol boats are detected. When the T-Craft detects enemy patrol boats it will return to the seabase until the threat is no longer present. Appendix C contains all designs and description of each variable.

a. Colombia Scenario

In order to explore the above-mentioned factors and its effects on the MOE, T-Craft Survival Rate, and Number of T-Craft Ashore, a regression model was developed using all input factors as predictors. The actual versus predicted plot depicted in Figure 17 shows that Escort, Return to Seabase (the use of the TTP), Speed, and Semi-Submersibles are statistically significant and explain 90 percent of the variability in the mean T-Craft survival rate. It is also important to note that the errors in this plot and the ones to follow are not normal, so significance tests are not exact. However, the p-values that are used are so low that the variables in the fitted models are significant.

In addition to identifying the variability in the model and the significant factors of the model, regression analysis also identifies those factors that have more statistical significance in the model. The higher the absolute value of the t-ratio, the more significant it is to the outcome of the MOE. For example, in Figure 17, Escorts[0], and Return to Seabase[0] are the most significant variables in the model. The negative coefficient associated with these variables means that the presence of these variables has a negative effect on the MOE. Therefore, without Escorts and the TTP the survivability of the T-Craft is significantly reduced. In addition, looking at the estimate column of the same figure shows by what amount the variable affects the MOE. Thus, in this case, the absence of Escorts (Escorts[0]) reduces the survivability of the T-Craft by 26 percent. Likewise, increasing the number of semi-submersibles in the fitted model reduces on average the survivability of the T-Craft by 4.9 percent per semi-submersible. The three highlighted outliers in the prediction plot represent the missions where escorts were not present and the number of enemy was minimal. This situation is one of the rare times that T-Craft survivability was high and escorts were not present.

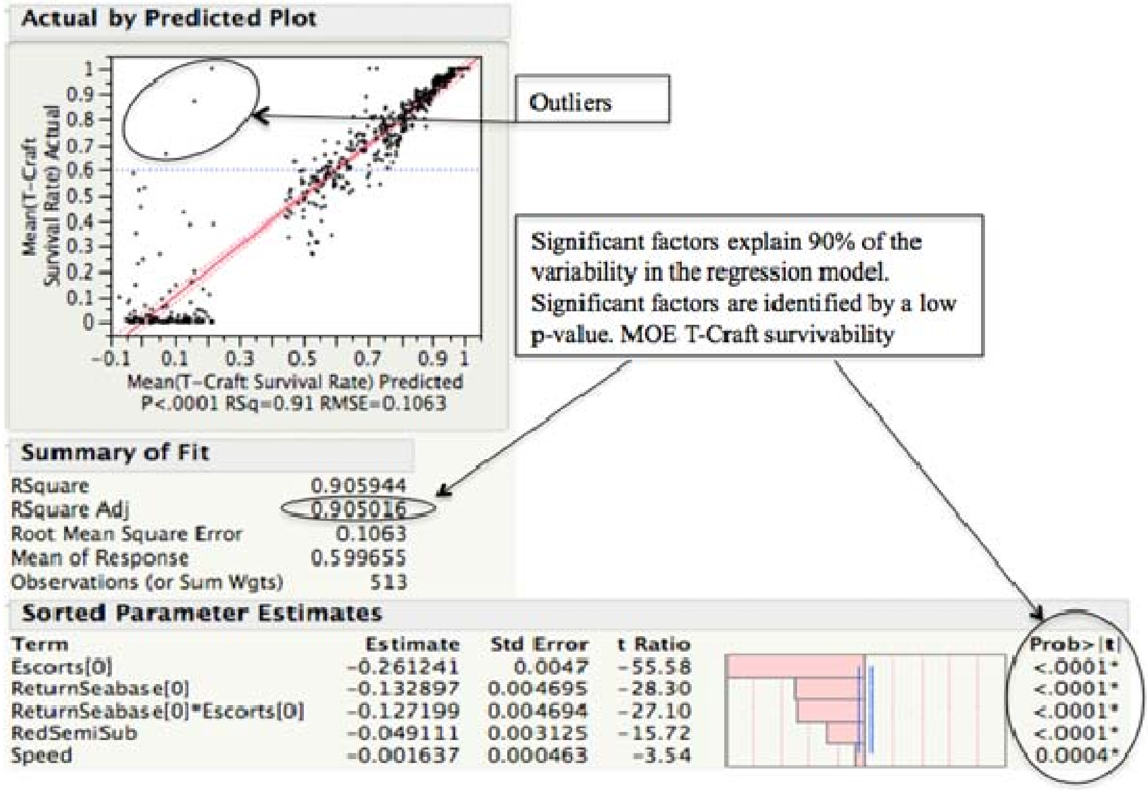


Figure 17. Regression plot and parameter estimates for the mean T-Craft Survival rate in the Colombia scenario question 1.

It is important to note that there is an interaction between Escorts and the TTP Return to Seabase. An interaction indicates that the change in the MOE caused by varying one parameter is dependent upon the value of another parameter. In an interaction plot, the MOE is on the y-axis and the factors involved in the interaction are on the x-axis and appear as separate lines. The matrix plot containing the interactions shows the high and low levels of the factor on the row and the trend in the MOE by changing the factor in the column. Evidence of interactions is shown as nonparallel lines (JMP8, 2009). Figure 18 shows the interaction effects for the fitted model with the survival MOE. The upper section in the figure shows the interaction between Escorts and Return to Seabase. From the figure, the following insights are gained:

- When Escorts are not present (red line) and the TTP is not used (0), the mean T-Craft Survivability rate is below one percent.
- When Escorts are not present and the TTP is used (1), the mean T-Craft Survivability rate rises above 50 percent.

- When Escorts are present (blue line) and the TTP is not used (0), the mean T-Craft Survivability rate rises to approximately 90 percent.
- When Escorts are present (blue line) and the TTP is not used (1), the mean T-Craft Survivability remains at approximately 90 percent.

The lower section displays the same relationship with the interaction terms. This finding shows that when the escorts are present the use of the TTP is statistically insignificant. This result is important because it signifies that if escorts are present there is no need to implement the TTP. The use of escorts alone increases the survivability of the T-Craft.

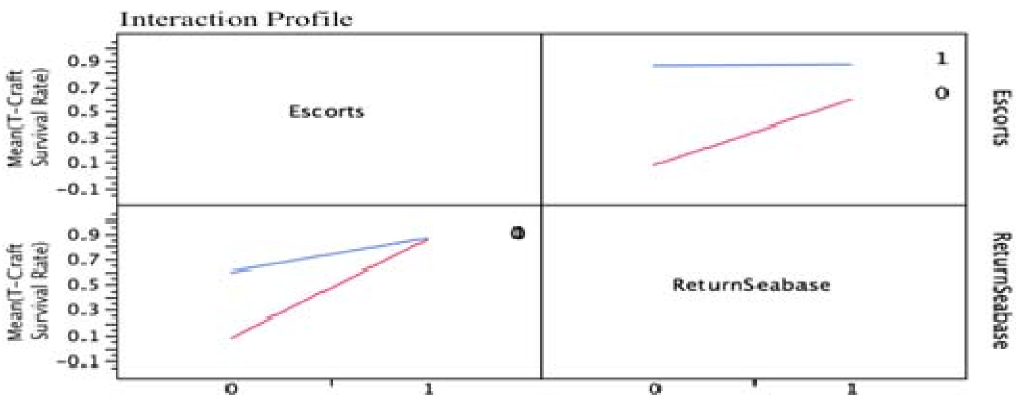


Figure 18. Interaction profile for the MOE mean T-Craft Survival Rate. The plot shows the interaction effects between Escorts and Return to Seabase for the Colombia scenario question 1.

Figure 19 shows the statistically significant variables that explain 89 percent of the variability in the mean number of T-Craft ashore. Both MOEs have factors in common, but, as can be seen, Number of T-Craft, Speed, and Red Patrol Boats are also significant in the later regression model. Also, the fitted model shows that there is an interaction between Escorts and Return to Seabase. The behavior in this model is much like the behavior in the previous model in that the presence of escorts produces the highest number of T-Craft ashore. So, when escorts are available, the TTP should not be used. Figure 20 graphs B and D show this relationship.

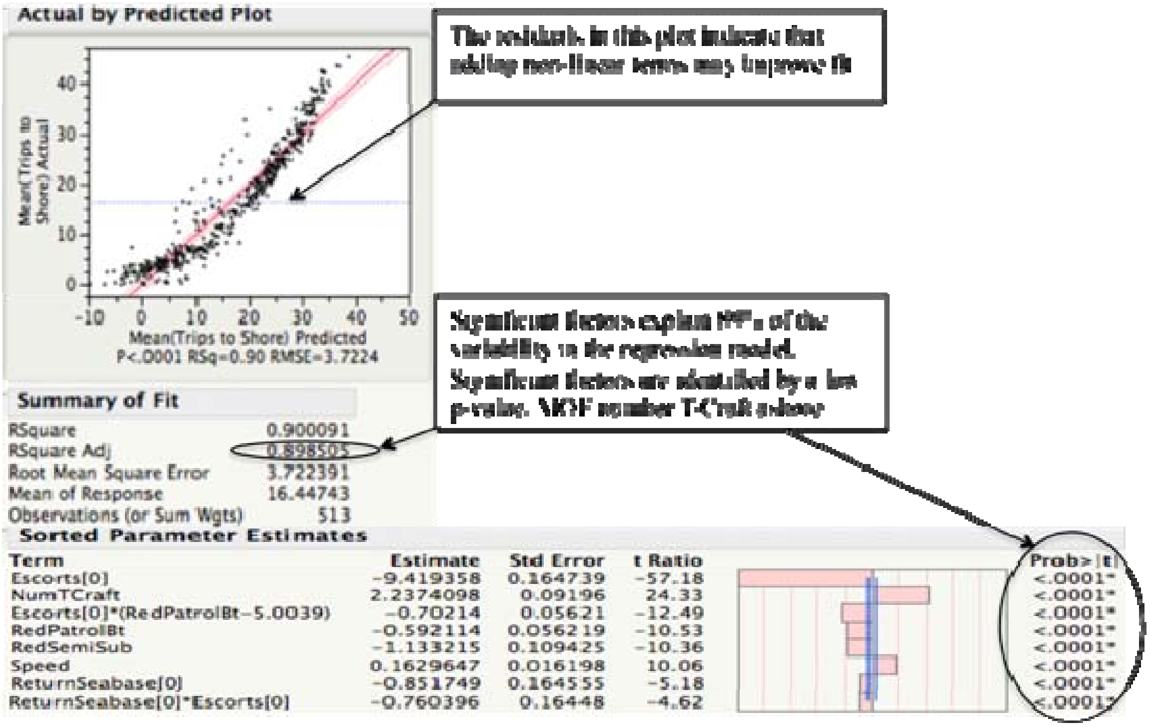


Figure 19. Regression plot and parameter estimates for the mean Number of T-Craft Ashore in the Colombia scenario question 1.

Figure 20 also shows another interaction relationship that seems somewhat intuitive. This interaction is between Escorts and Red Patrol Boats (graphs A and C). From graph A the following insights are obtained:

- When Escorts are not present (red line) and there are zero Red Patrol Boats, the number of T-Craft Ashore is greater than 10. (Semi-submersibles are present in the model)
- When Escorts are not present and there are 10 Red Patrol Boats, the number of T-Craft Ashore drops to zero.
- When Escorts are present (blue line) and there are zero Red Patrol Boats, the number of T-Craft Ashore is greater than 20.
- When Escorts are present (blue line) and there are 10 Red Patrol Boats, the number of T-Craft Ashore is greater than 20.

Graph C depicts the same relationship. This interaction shows that the number of T-Craft Ashore is greater than 20 regardless of the number of Red Patrol Boats. Without escorts the number of T-Craft ashore drops significantly. This interaction relationship reinforces

the importance of escorts in a threat environment. It translates to mission success in that more T-Craft ashore means more combat power or sustainment ashore.

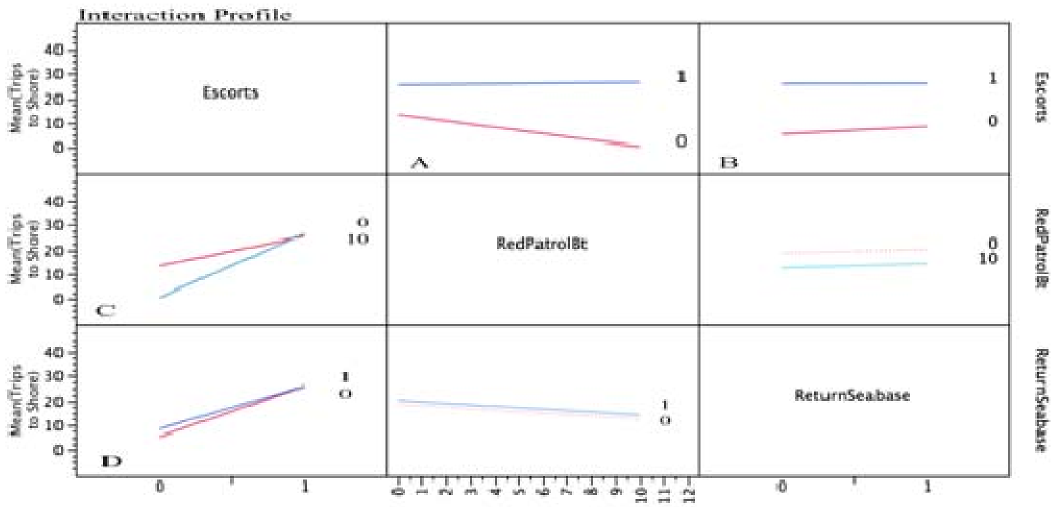


Figure 20. Interaction profile for the MOE mean Number of T-Craft Ashore. The plot shows the interaction effects in the fitted model for the Colombia scenario question 1.

After running this scenario, the variable Armed is not significant to either MOE. This finding means that the survivability of the T-Craft or number of T-Craft ashore is not significantly dependent on having a weapon system on board in this scenario. The presence of the escorts or the use of the TTP was sufficient in keeping the T-Craft safe. Figure 21 shows a one-way analysis of variance plot (ANOVA) depicting the relationship between the three variables: Armed, Escorts, and Return to Seabase, and the survivability MOE. It also contains density plots that compare variable distributions and how they affect survivability. The red line in the plot represents the variable being inactive. The blue line represents the variable being active. The green diamonds in the plot represents the mean value of the variable over the distribution in that state. So, for example, the green diamonds in the Armed graph shows the mean survival rate with or without weapons as 60 percent. ANOVA tests allow the testing of two or more variables and the comparison of means in order to identify how a continuous response (MOE) distributes differently across groups defined by the variables. More information can be

found in the user manual of JMP8. The overlapping lines in the figure reinforce the point that Armed in this scenario was not significant.

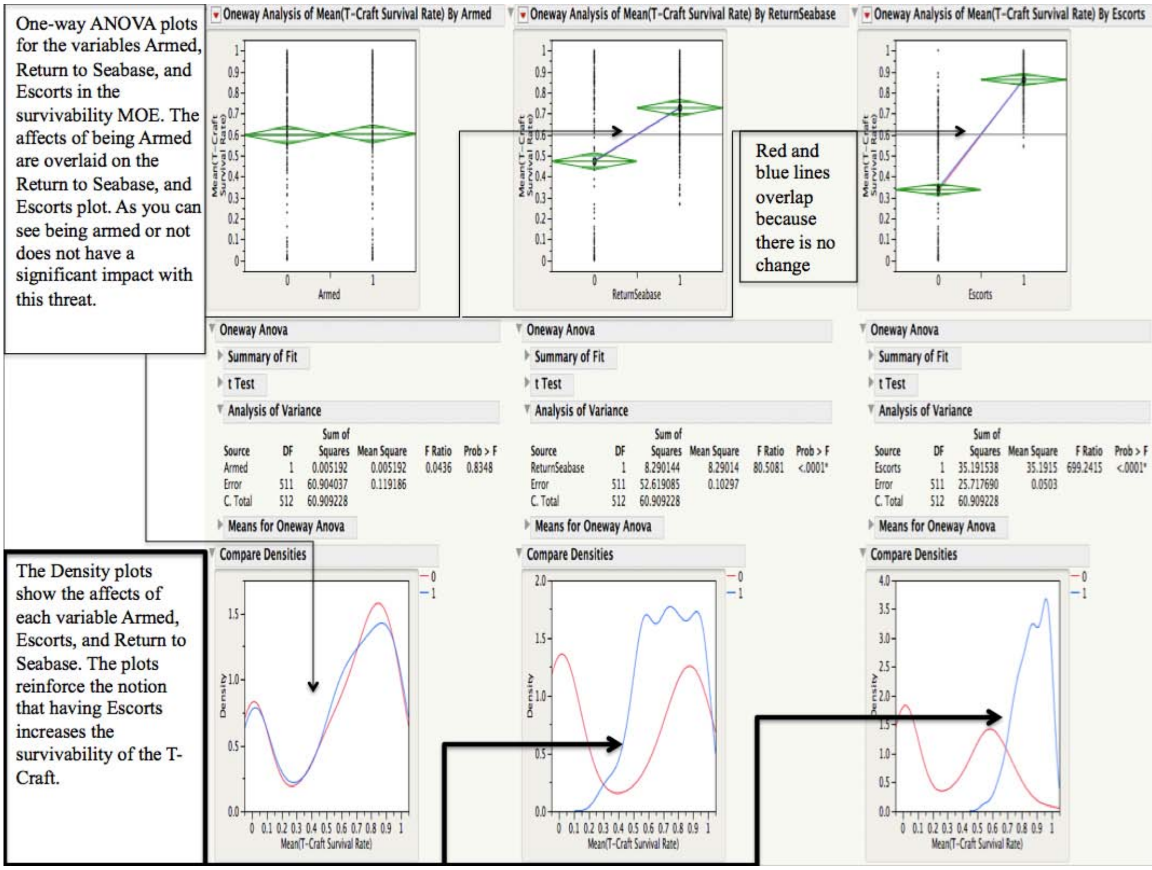
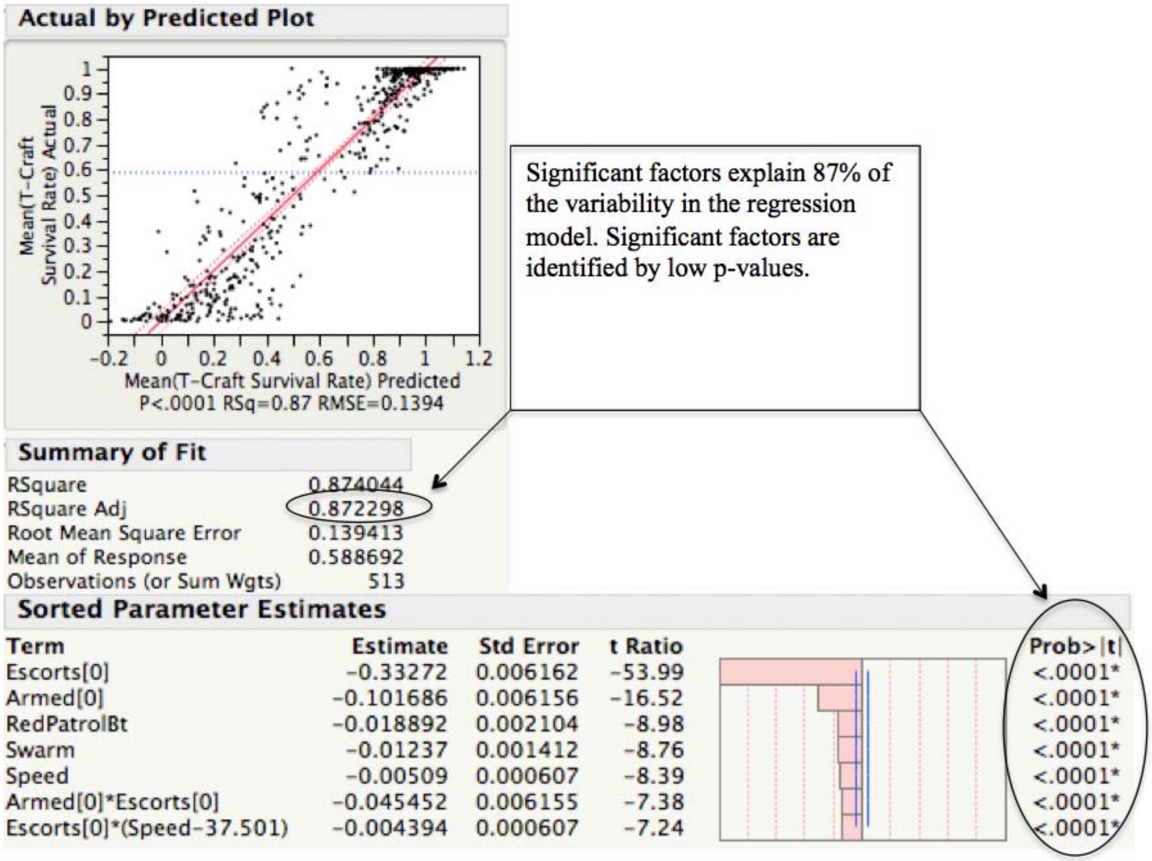


Figure 21. ANOVA plots of the MOE mean T-Craft Survival Rate and the variables Armed, Escorts, and Return to Seabase.

b. *Malaysia Scenario*

The analysis for the Malaysia scenario was conducted in much the same manner as the Colombia scenario. However, in this scenario a different threat is present and the distance to the shore has been significantly increased. As a result, the variables Escorts, Armed, Red Patrol Boat, Swarm, and Speed appear to be significant, explaining 87 percent of the variability in the MOE mean T-Craft Survival Rate. Similar to the findings in the Colombia scenario, escorts are the most significant factor in increasing the survivability of the T-Craft. In addition, the T-Craft being armed also contributes significantly to the survivability rate of the T-Craft. The T-Craft being armed is significant in this scenario because of the pure surface threat. Unlike the Colombia

scenario, where the semi-submersibles are hard to detect, the swarm craft are much easier to detect. Figure 22 shows the actual versus predicted plot and the sorted parameters for the MOE mean T-Craft Survival Rate.



Summary of Fit

RSquare	0.874044
RSquare Adj	0.872298
Root Mean Square Error	0.139413
Mean of Response	0.588692
Observations (or Sum Wgts)	513

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Escorts[0]	-0.33272	0.006162	-53.99	<.0001*
Armed[0]	-0.101686	0.006156	-16.52	<.0001*
RedPatrolBt	-0.018892	0.002104	-8.98	<.0001*
Swarm	-0.01237	0.001412	-8.76	<.0001*
Speed	-0.00509	0.000607	-8.39	<.0001*
Armed[0]*Escorts[0]	-0.045452	0.006155	-7.38	<.0001*
Escorts[0]*(Speed-37.501)	-0.004394	0.000607	-7.24	<.0001*

Figure 22. Regression plot and parameter estimates for the MOE mean T-Craft Survival Rate in the Malaysia scenario question 1.

As for the MOE Number of T-Craft Ashore, 85 percent of the variability is explained by the following variables: Escorts, Number of T-Craft, Speed, and Armed. Again, the T-Craft being armed proved to be significant. Figure 23 shows the actual versus predicted plot and the sorted parameters for the MOE mean Number of T-Craft Ashore.

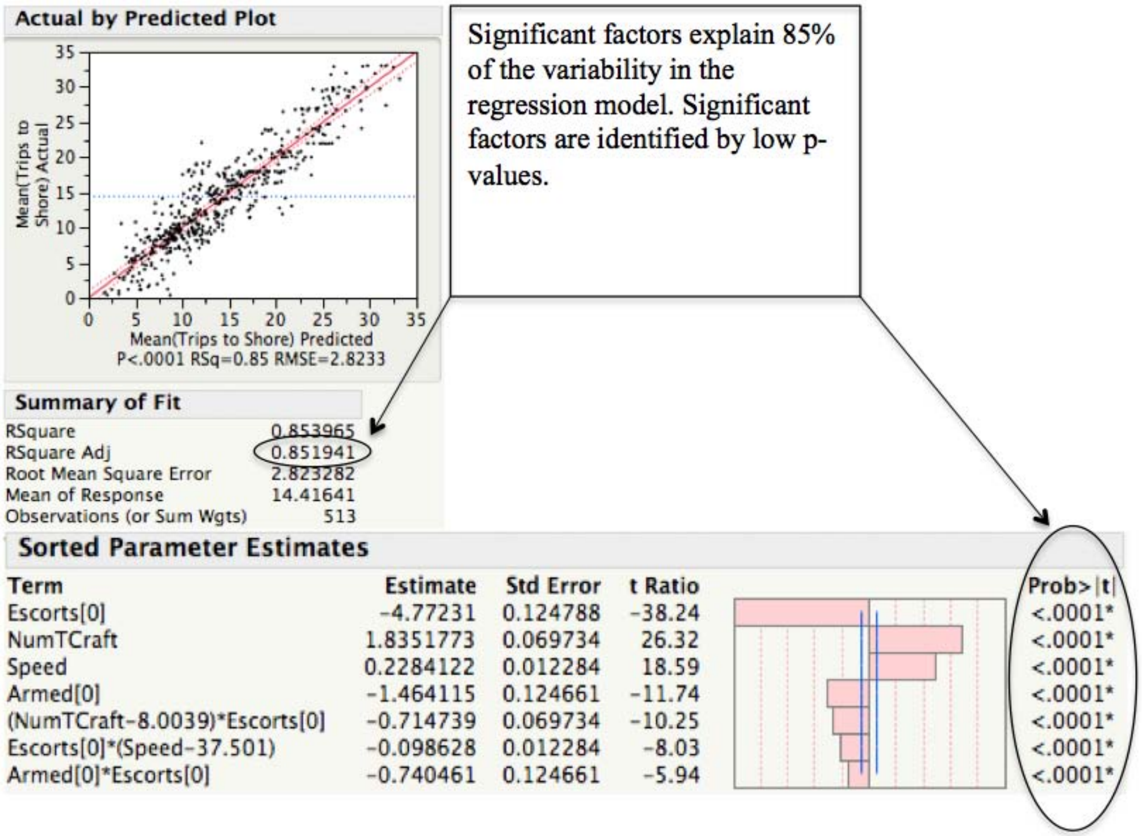


Figure 23. Regression plot and parameter estimates for the MOE mean Number of T-Craft Ashore in the Malaysia scenario question 1.

The Malaysia scenario contains several interaction terms. Escorts are a consistent variable in all of the interaction terms. In each interaction, survivability increases when escorts are present. One interaction term that was of particular interest was the interaction between the variables Armed, and Escorts. This interaction was significant to both fitted models and it was interesting to see if it had the same properties as the Escort and Return to Seabase interaction in the previous scenario. Figure 24 shows that the interaction relationship between Armed and Escorts is additive. Having both features enhances both the survivability of the T-Craft and the number of T-Craft ashore.

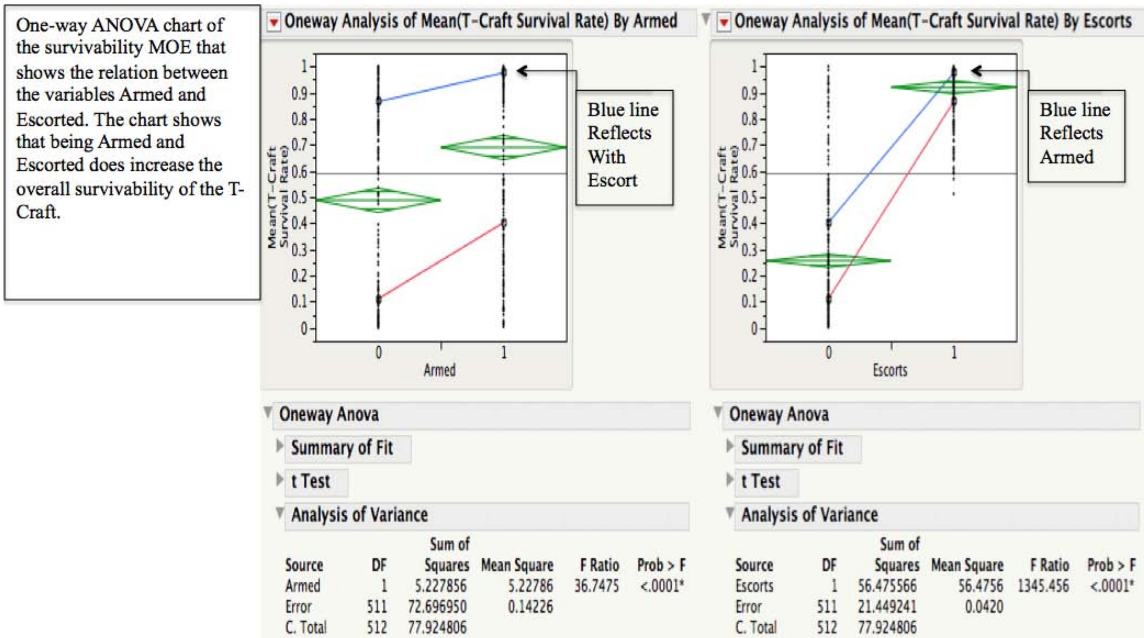


Figure 24. ANOVA chart of the MOE mean T-Craft Survival Rate showing the relation between the variables Armed and Escorted.

c. Summary

The intent of question one was to address whether the T-Craft should be armed or not, escorted or not, and armed and escorted or not. From the analysis of the Colombia and Malaysia scenarios, the use of escorts proved to be significant in both scenarios. The presence of escorts in both models improved both MOEs. The default vessel mix for escorts was: five LCS_SWs, two LCS_ASWs, and four MH-60s. The answer to the question of the T-Craft being armed was clear in the Malaysia scenario. However, in the Colombia scenario, the T-Craft having a weapon system did not appear to have a significant effect on either MOE. This finding is a result of the strong escort presence in the Colombia scenario and the subsurface threat in that environment. The Malaysia scenario contained a pure surface threat, and as a result, both variables Armed and Escorted proved to be significant. With that, the next section will carry this information forward in the attempt to further identify a good T-Craft employment method in these types of environments.

2. How Should the Transformable Craft be Employed When a Threat Exists?

The analysis in this section is geared toward gaining insights into how the T-Craft should be employed when a threat exists. The data are explored to identify any indicators as to what mix of escort vehicles will increase the survivability of the T-Craft, or which weapon system of the two recommended has the greater impact on T-Craft survivability. The analysis for this section includes a few more variables that helped explore many more relationships within each scenario. Each scenario is covered in turn.

a. Colombia Scenario

The run of the Colombia scenario produced the following results. With the increased number of variables, the output contained several more variables that appear to be significant to the MOE mean T-Craft Survival Rate. Figure 25 shows the prediction plot and sorted parameter list that lists the factors that explain 83 percent of the variability in the MOE describing T-Craft survivability. From the figure, it is possible to see that the semi-submersible threat is very significant insofar as it impacts the survivability of the T-Craft. As for the controllable factors, the MH-60 is the most significant factor listed. Based on the characteristics of the MH-60, it ranks very high due to its ability to detect and engage the enemy along the shoreline, as well as to detect and engage enemy threats at sea. The MH-60 flies a search pattern that allows it to go close enough to shore to detect semi-submersibles and that also allows it to fly along the sea-lanes to pick up any other enemy presence. Other controllable factors that appear to be significant are Speed, the Number of T-Craft, and LCSs.

In order to gain insights into the performance of the weapon systems, the variables Weapon 1 (MK110) and Weapon 2 (30mm cannon) are included in the regression model. The two variables have a high p-value, which indicates that they do not have a statistically significant impact on the MOE. However, there are still insights to be gained by examining these two variables. The parameter list shows that Weapon 1 has a positive coefficient, while Weapon 2 has a negative coefficient. The positive coefficient means that when weapon one is active in the model the MOE mean T-Craft Survival Rate

is slightly improved. The negative coefficient on Weapon 2 results in a decrease in the survivability MOE when Weapon 2 is the only active weapon. This result is because Weapon 1 has a much higher effective range and higher rate of fire than Weapon 2. With this information, if forced to choose, the recommendation would be for Weapon 1.

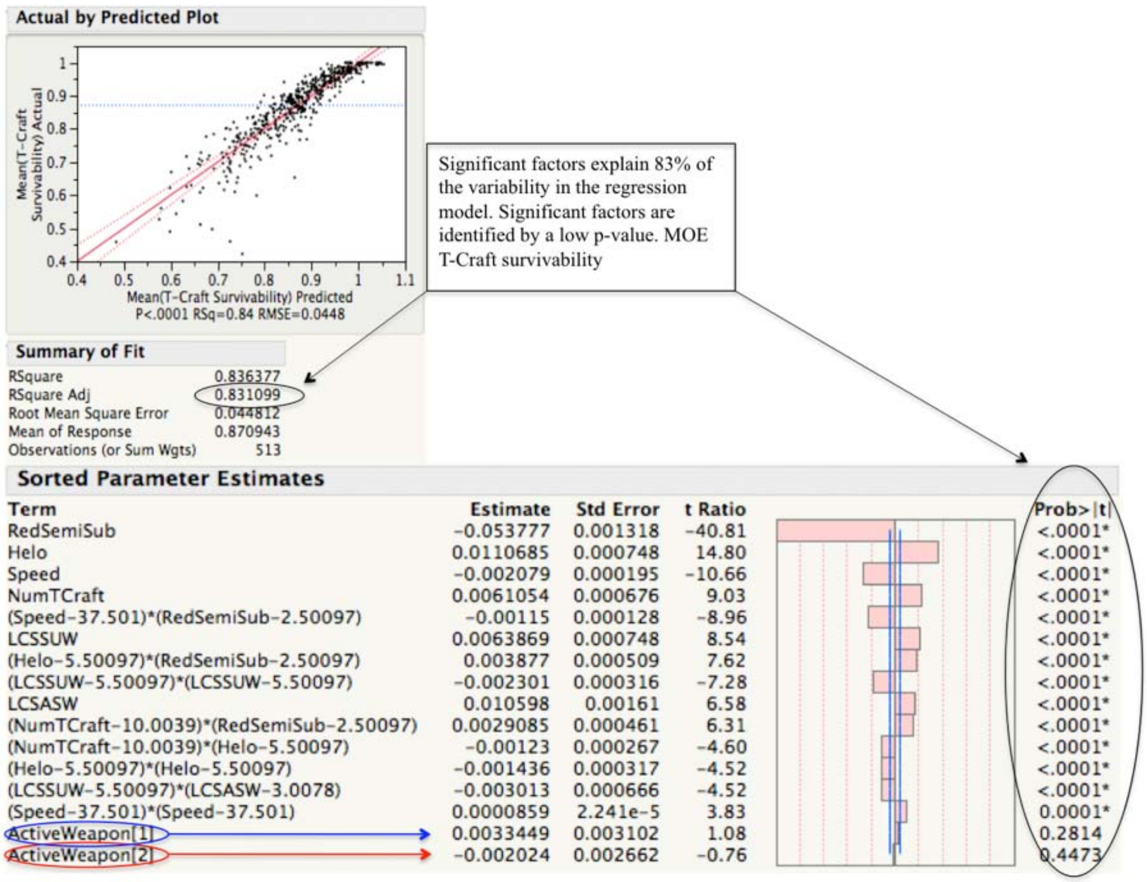


Figure 25. Regression plot and parameter estimates for the mean T-Craft Survival Rate in the Colombia scenario question 2.

While the number of friendly vessels all have a positive coefficient associated with them in the fitted model, it is interesting to see that speed has a negative coefficient. As speed increases past 30 knots, the MOE begins to decrease below 90 percent. This fact is interesting because speed was thought to be the main factor that would improve the survivability of the T-craft. Figure 26 shows the plot of the speed distribution and its impact on T-Craft survivability. The plot provides a more detailed look at the relationship between speed and survivability. Each dot in the plot represents the mean survival rate of a simulated mission. The red line depicts the mean survival rate

over the entire distribution. The green line connects the means of the different factor levels. As speed increases from 20 knots survivability decreases. At speeds above 30 knots, the survivability decreases below the mean. Also, at speeds greater than 30 knots there is more variance in the distribution, i.e., more dots appear further away from the mean. Therefore, the recommended operating range of the T-Craft when a threat is present appears to be between 20 and 30 knots, in this scenario. In this speed range, the T-Craft is traveling with its escorts and not outrunning them. Traveling within this speed range increases the likelihood of a protective barrier around the T-Craft as it conducts its mission.

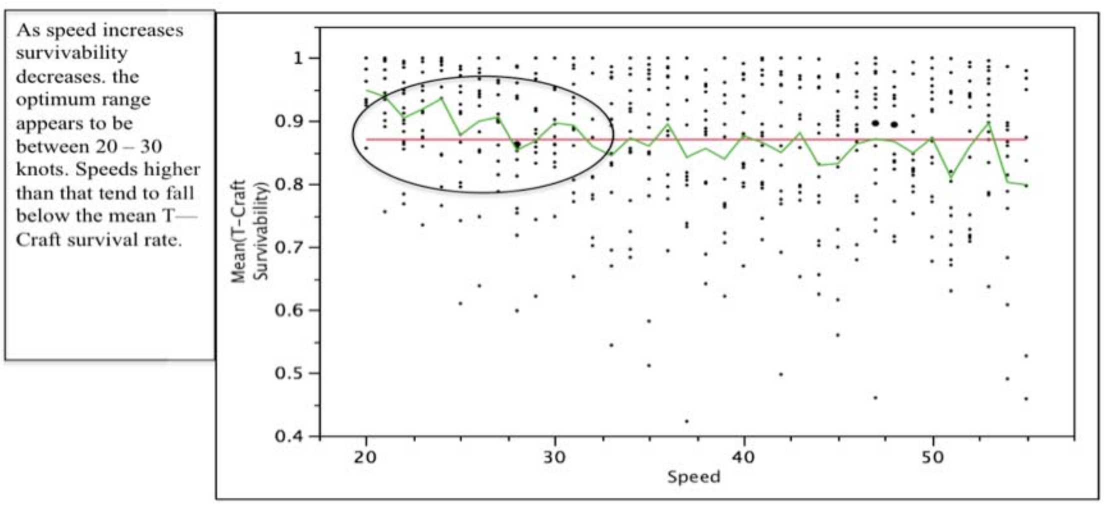


Figure 26. Distribution plot showing the relation between Speed and the MOE mean T-Craft Survival Rate.

The analysis of the MOE mean Number of T-Craft Ashore produced similar results to those of the survivability MOE. Figure 27 shows the predicted plot and parameters that explain 88 percent of the variability in the MOE. It is interesting to find that, unlike the survivability MOE, Speed is positively correlated to the number of T-Craft ashore. As speed increases, more T-Craft will land ashore. The prediction profiler shows that speeds in excess of 35 knots generate only a few more T-Craft ashore than at slower speeds. This finding results from the T-Craft outrunning their escorts and being exposed to enemy actions; it further confirms the previously-stated recommended

operating range. Figure 28 shows the relationship with speed and number of T-Craft ashore using the prediction profiler. The profiler highlights the diminishing return speed has on the number of T-Craft ashore. As speed is increased from 25 to 35 knots, the number of T- Craft ashore rises by four. Increasing speed from 35 to 45 knots only results in an increase of two more T-Craft ashore.

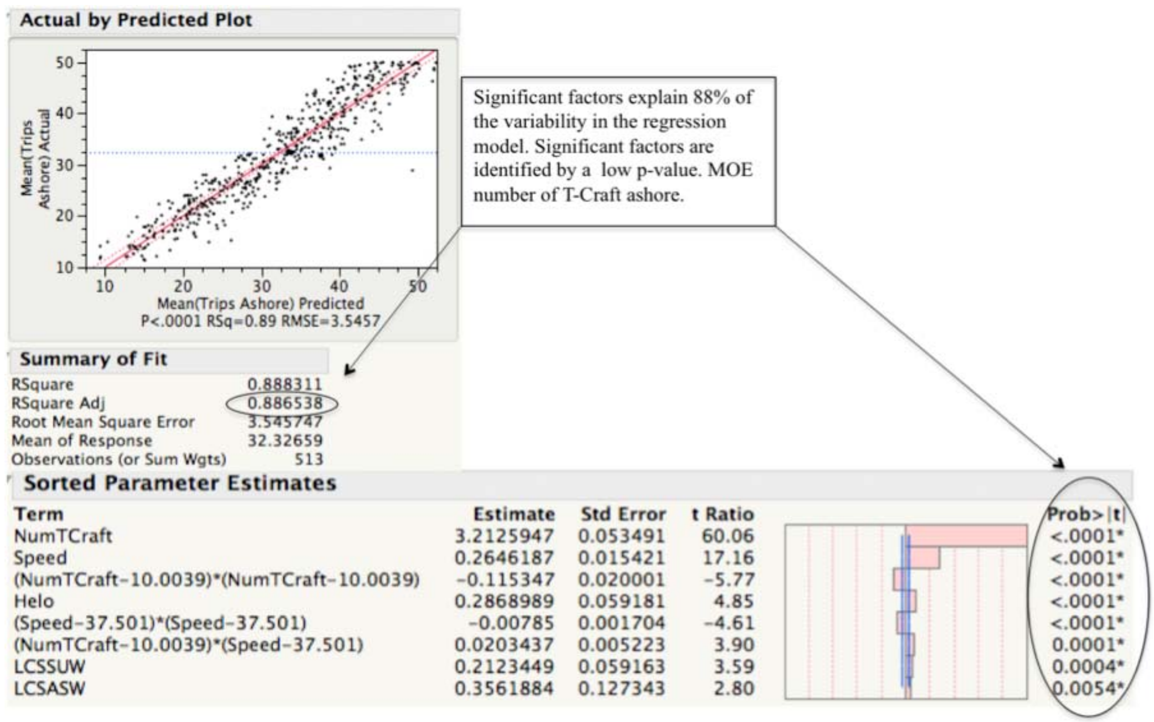


Figure 27. Regression plot and parameter estimates for the mean Number of T-Craft Ashore in the Colombia scenario question 2.

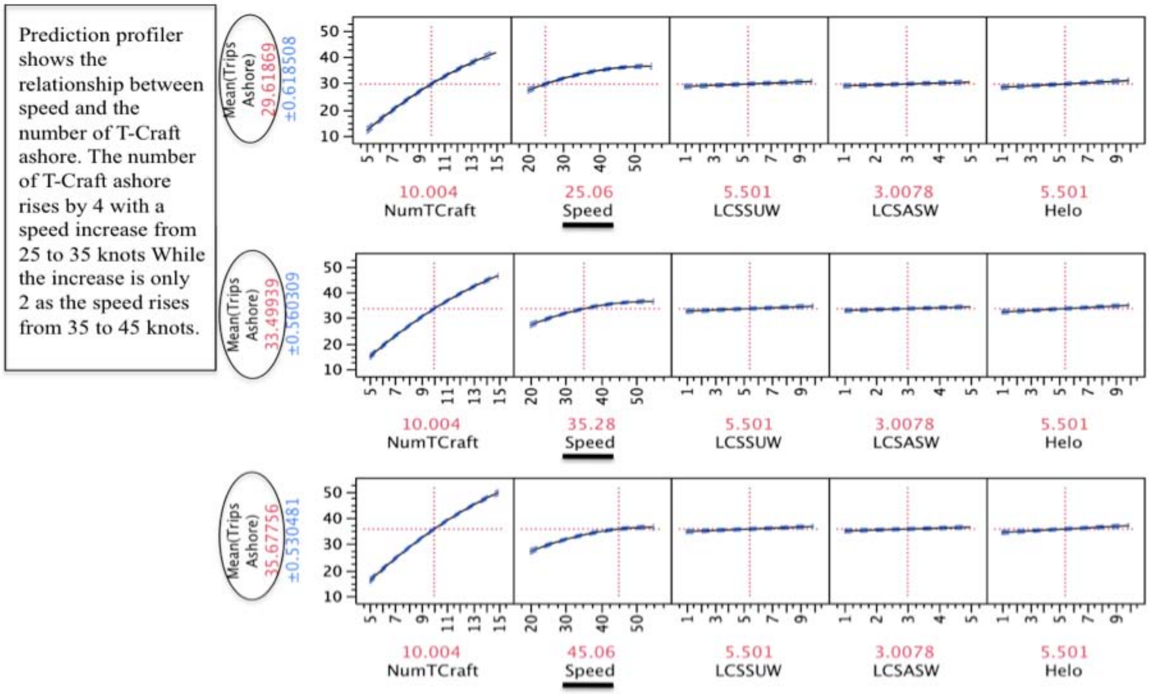


Figure 28. Prediction plots for the MOE mean Number of T-Craft Ashore. This graph compares the relationship between Speed and the number of T-Craft ashore.

In answering the first question, a default mix of escort vehicles was determined and used for each simulation run. In this section, a closer look is taken at each escort entity in order to determine an effective mix to improve T-Craft survivability. Figure 29 reflects the distribution plots of each of the escort vehicles and their impact on T-Craft survivability. The red line represents the mean survivability across the entire distribution. The green line connects the factors at each point. There is a significant increase in survivability when the number of LCS_SW increases from one to two and the number of MH-60s increase from three to four. The increase in survivability with the LCS_ASW appears to be most significant when there are at least three present. In order to maintain a higher T-Craft survival rate, there should be: at least two LCS_SW, but four or more LCS_SW are preferred; three or more LCS_ASW; and five or more MH-60s. Using these values creates a survivability rate of about 90 percent or higher in the stressing scenario models.

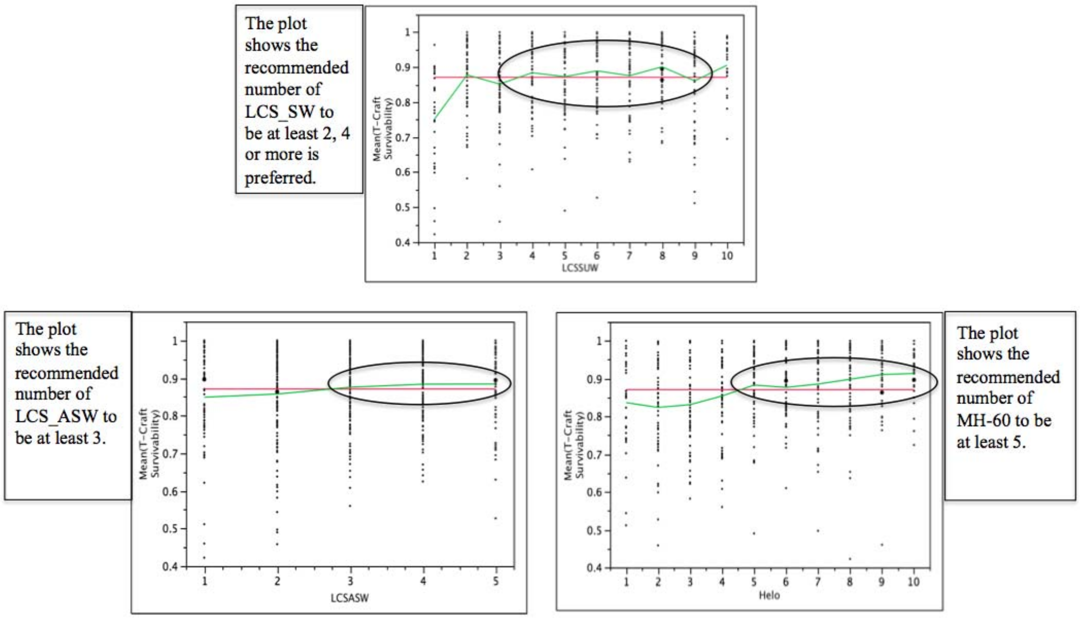


Figure 29. Distribution plots of the mean T-Craft Survival Rate and LCS_SW, LCS_ASW, and MH-60s in the Colombia scenario. The plot shows the recommended range when determining escort mix.

The process was repeated when trying to determine the optimum number of T-Craft. Figure 30 shows the relationship between the number of T-Craft and T-Craft survivability. This plot shows that when the number of T-Craft is greater than ten, survivability is highest.

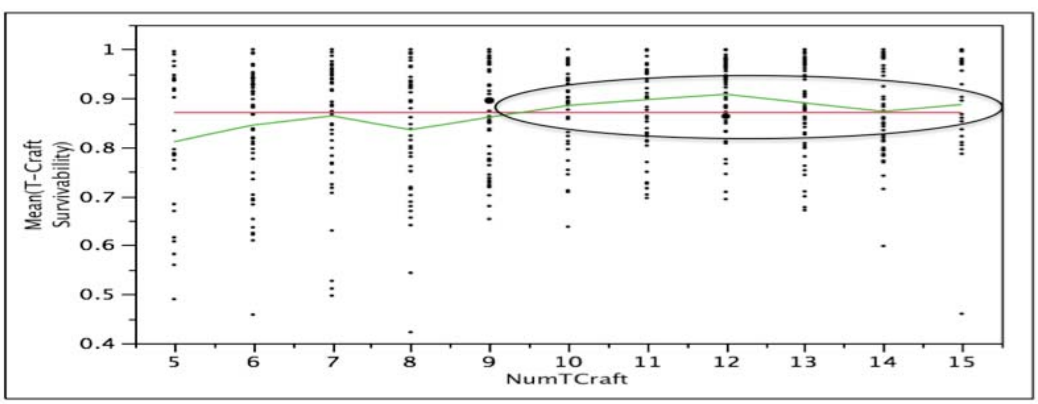
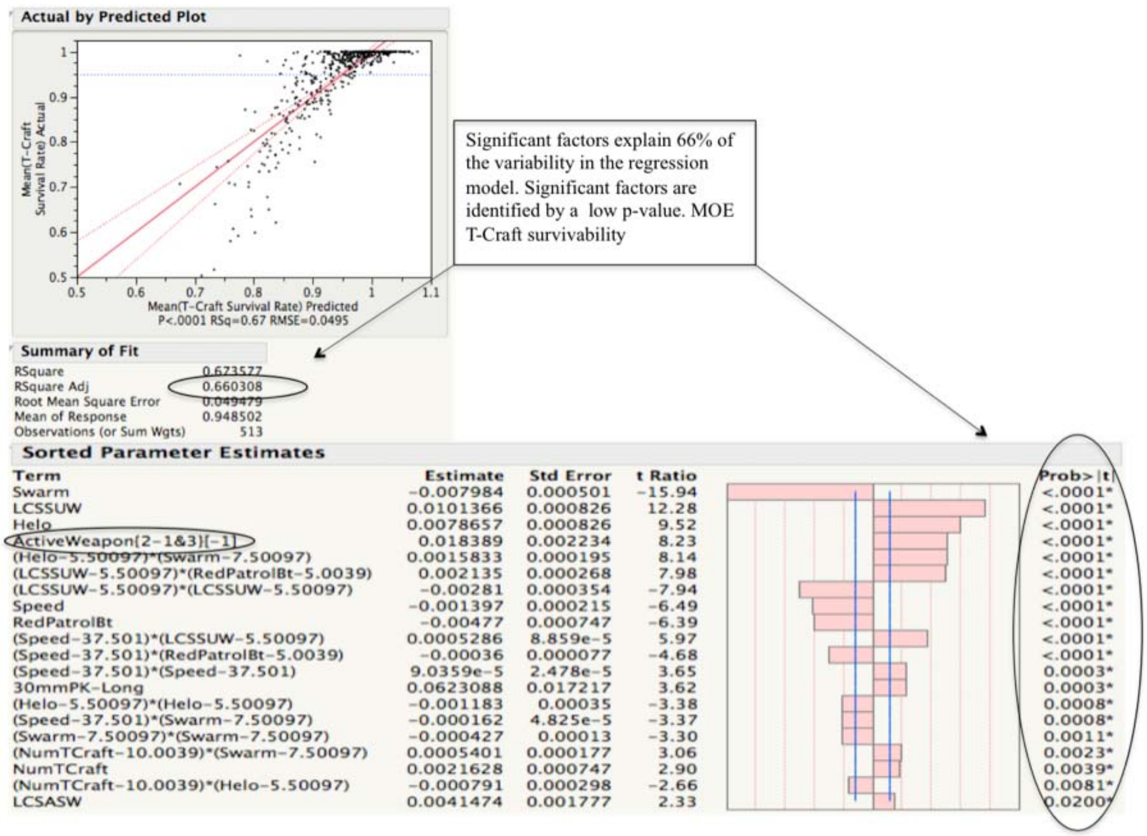


Figure 30. Distribution plots of the mean T-Craft Survival Rate and number of T-Craft. The plots show the recommended range when determining number of T-Craft.

b. Malaysia Scenario

As before, the Malaysia scenario is different from the Colombia scenario. The seabase in this scenario is 150 nm from shore and the threat is purely surface. Due to the questions that are being addressed, the number of factors in this scenario was increased as well. Figure 31 shows the predicted plot and sorted parameters that explain 72 percent of the variability in the survivability MOE. In this model, the controllable factor LCS_SW appears to be the most significant factor. The factor LCS_SW is followed by the MH-60. In this scenario, both factors are able to effectively engage the enemy threat. Unlike the semi-submersibles that are almost undetectable by the LCSs due to range, the swarm craft are easily detected by the LCSs. As before, the MH-60 flies in a search pattern that allows it to detect and engage enemy threats along the coast, as well as out to sea. The regression model for the MOE mean Number of T-Craft Ashore looks very similar to the survivability model.



Summary of Fit	
RSquare	0.673577
RSquare Adj	0.660308
Root Mean Square Error	0.049479
Mean of Response	0.948502
Observations (or Sum Wgts)	513

Term	Estimate	Std Error	t Ratio	Prob>|t|
Swarm	-0.007984	0.000501	-15.94	<.0001*
LCSSUW	0.0101366	0.000826	12.28	<.0001*
Helo	0.0078657	0.000826	9.52	<.0001*
ActiveWeapon{2-1&3}[-1]	0.018389	0.002234	8.23	<.0001*
(Helo-5.50097)*(Swarm-7.50097)	0.0015833	0.000195	8.14	<.0001*
(LCSSUW-5.50097)*(RedPatrolBt-5.0039)	0.002135	0.000268	7.98	<.0001*
(LCSSUW-5.50097)*(LCSSUW-5.50097)	-0.00281	0.000354	-7.94	<.0001*
Speed	-0.001397	0.000215	-6.49	<.0001*
RedPatrolBt	-0.00477	0.000747	-6.39	<.0001*
(Speed-37.501)*(LCSSUW-5.50097)	0.0005286	8.859e-5	5.97	<.0001*
(Speed-37.501)*(RedPatrolBt-5.0039)	-0.00036	0.000077	-4.68	<.0001*
(Speed-37.501)*(Speed-37.501)	9.0359e-5	2.478e-5	3.65	0.0003*
30mmPK-Long	0.0623088	0.017217	3.62	0.0003*
(Helo-5.50097)*(Helo-5.50097)	-0.001183	0.00035	-3.38	0.0008*
(Speed-37.501)*(Swarm-7.50097)	-0.000162	4.825e-5	-3.37	0.0008*
(Swarm-7.50097)*(Swarm-7.50097)	-0.000427	0.00013	-3.30	0.0011*
(NumTCraft-10.0039)*(Swarm-7.50097)	0.0005401	0.000177	3.06	0.0023*
NumTCraft	0.0021628	0.000747	2.90	0.0039*
(NumTCraft-10.0039)*(Helo-5.50097)	-0.000791	0.000298	-2.66	0.0081*
LCSASW	0.0041474	0.001777	2.33	0.0200*

Figure 31. Regression plot and parameter estimates for the T-Craft Survival Rate in the Malaysia scenario question 2.

The findings in the Malaysia scenario show each factor having a similar relationship as found in the Colombia scenario with respect to speed, i.e., as speed increases past 33 knots, T-Craft survival rate starts to decrease. As for the number of T-Craft and escorts, the numbers are also close to the same. Figure 32 shows the relationship between the distributions of the escorts with the survival MOE and the relationship of the T-Craft and the survival MOE. With seven or more T-Craft, two or more LCS_SW, five or more MH-60s, and one or more LCS_ASW, a survival rate of approximately 90 percent or higher will be maintained with a significant threat present. In this scenario, as in the Colombia scenario, there is a significant jump in survival rate when the LCS_SW rises from one to two. The rise in survivability is a result of the enemy threat coming from multiple directions. Having two or more LCS_SWs were needed to create a protective lane through which the T-Craft could transit.

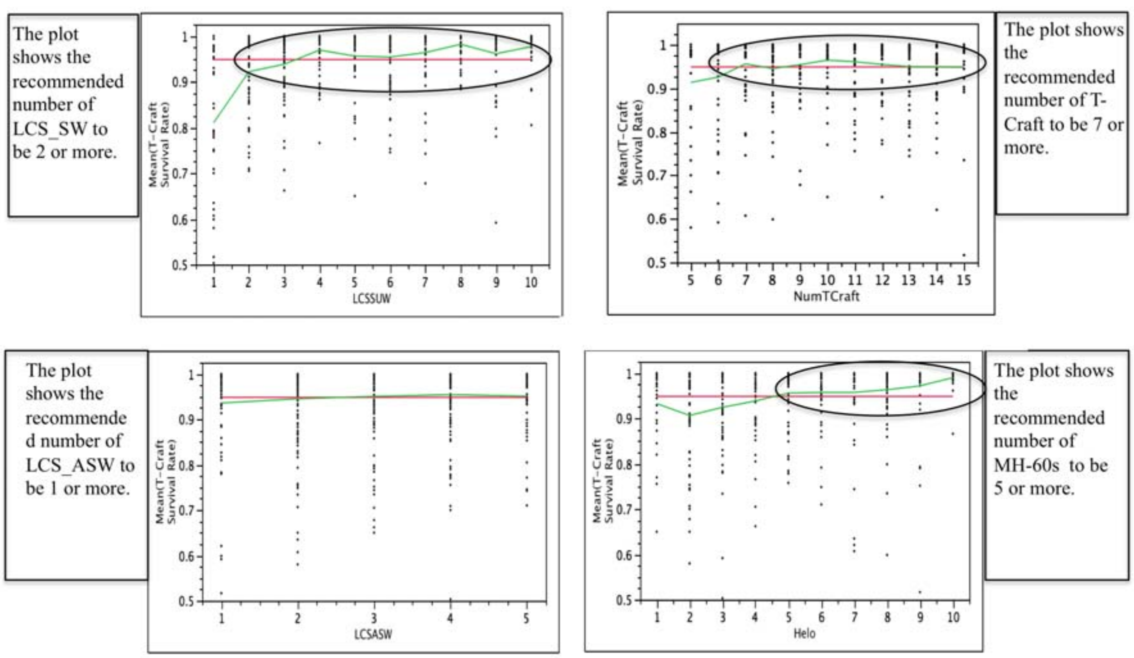


Figure 32. Distribution plots of the mean T-Craft Survival Rate and T-Craft LCS_SW, LCS_ASW, and MH-60s in the Malaysia scenario. The plot shows the number at which survivability increases beyond 90 percent.

The weapon systems performed as anticipated in this scenario. Having both weapons active was most significant. However, Weapon 1 appeared more effective against the swarm and patrol boat threat. From the parameter list in Figure 33, active Weapon (2 – 1&3) means that Weapon 2 had very little impact on the survivability of the T-Craft, as compared to Weapon 1 or both being used. In this scenario the targets were at a greater range and Weapon System 1 has a longer effective range. This capability allowed for the T-Craft to engage targets at a much greater distance.

c. Summary

The initial intent of question two was to find mixes of weapon systems and escort vehicles that will enhance the survivability of the T-Craft when a threat exists. In conducting the analysis of the question it was discovered that Weapon 1 was most effective in protecting the T-Craft in each of the scenarios. The attributes of speed turned out to be counterintuitive; speed was initially thought to be the main contributor to the survivability of the T-Craft. However, the case is that when a threat is present, it is better for the T-Craft to stay with its escorts in order to best perform its mission. The recommended number of escorts, and T-Craft were close if not the same in each scenario. In the Colombia scenario, the numbers were ten or more T-Craft, two or more LCS_SW, three or more LCS_ASW and five or more MH-60s; and in the Malaysia scenario, seven or more T-Craft, two or more LCS_SW, one or more LCS_ASW, and five or more MH-60s. These resulted in survival rates of over 90 percent in each scenario.

C. FURTHER INSIGHTS

This section addresses some important points that emerged during the analysis. Each point was consistent throughout the analysis of each question, and proved to be points of interest as conclusions and insights were developed. This highlights one of the main characteristics of data farming. So much information was varied and run through the models that in looking for one data point, several more nuggets of information were discovered. This information proved to be both useful and relevant, especially in understanding the significance of shoreline threats of semi-submersibles and swarm craft.

1. Semi-submersibles

The semi-submersible threat is much like that of the improvised explosive devices (IED) currently being used in the combat zones of Iraq and Afghanistan. If forces are deployed to an area where this threat is present, measures must be taken to defeat the threat. After the results of the experimental designs were analyzed, a smaller follow-on study was conducted to see if there was a way to improve T-Craft survivability against semi-submersibles. The design simulated a more sophisticated communication and identification capability that is linked to the weapon system. The results of the analysis show that by improving sensors and communication links on the T-Craft, the survivability of the T-Craft increased. Figure 33 shows these results. The red line represents the effectiveness of the T-Craft weapons against the semi-submersibles without communication links, and the blue line represents the effectiveness of the weapons with communications links. Weapon 1 appears to be more effective than Weapon 2.

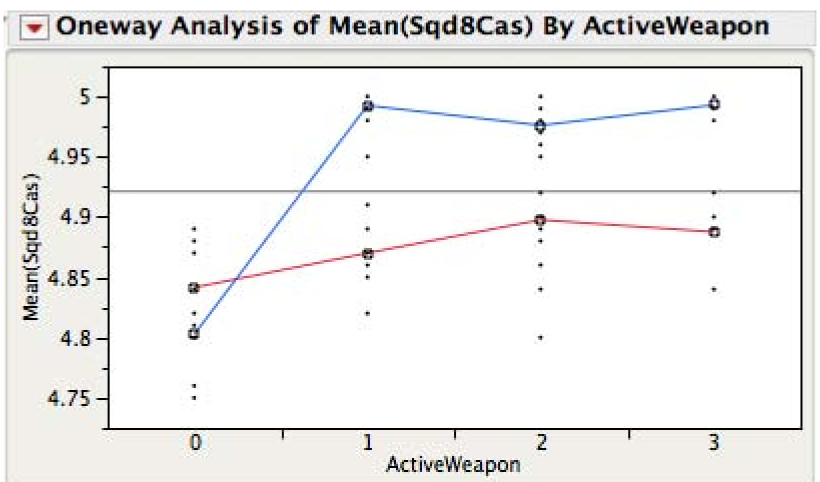


Figure 33. ANOVA plot showing the relation between Semi-submersibles and the effectiveness of weapons with or without a communication link.

2. Swarm Craft

In the Malaysia scenario, the coastal swarm boats turned out to be the most significant threat. Under normal operations, the LCS would not go in waters shallower than 30 ft due to its draft. In an attempt to accurately display this restriction, the LCSs

were programmed to stop approximately six miles short of the shoreline in order to simulate the restriction. However, since this is a modeling environment, the restriction was overridden at times when the LCS detected an enemy threat and pursued it. This situation is a concern because in the same six-mile threshold the T-Craft is likely to conduct its transformations from SES to ACV and back. The transformation is another function that leaves the T-Craft vulnerable. This situation seemingly creates a zone approximately six to ten miles off the coast that leaves the T-Craft most vulnerable to attack. Further tests should be done to model the shoreline region in order to see if restrictions on the LCS cause the threat to be more significant and, if so, what courses of action can be taken to address this problem.

V. CONCLUSIONS AND RECOMMENDATIONS

A. RESEARCH SUMMARY

This research set out to determine how best to protect the T-Craft in a hostile environment. The T-Craft was modeled with weapons, LCS escorts, and MH-60s as a means of enhancing survivability. Through the use of realistic scenario simulations, this study produced detailed analysis regarding the escort size and composition, along with the effects of weapon systems as it pertains to T-Craft survival. It also provided a framework for the future use of agent-based models, such as MANA, in exploring similar or related topics. The results of this thesis provide insights into how the T-Craft should be deployed. Furthermore, the simulation built for this research can serve as the foundation for many additional studies.

B. RECOMMENDATIONS

Seabasing is developing as a dominant concept for military operations in the 21st century and will be at the core of joint operations abroad. The T-Craft is intended to provide "game-changing capabilities" for seabasing operations, substantially outperforming any seabase connector in the Navy's current inventory. Through the use of simulation, state-of-the-art experimental design, and advanced data analysis, over 200,000 seabasing missions were analyzed by varying the number of T-Craft, its capabilities (e.g., speed), the types of weapon systems it carries, its tactics, as well as escort mixes and threat level, in order to determine what combinations obtain the highest survivability and throughput rate for the T-Craft. From the analysis of the scenarios conducted in Chapter IV, the following conclusions were made.

1. Should the T-Craft Have Its Own Organic Weapons System?

The answer to the question of the T-Craft being armed was clear in the Malaysia scenario. However, in the Colombia scenario, the T-Craft having a weapon system did not appear to have a significant effect on either MOE. This finding is a result of the subsurface threat in that environment and the robust escort package. The Malaysia

scenario contained a pure surface threat, and both variables armed and escorted proved to be significant. Through further analysis, the T-Craft being armed did in fact improve survivability. Because of its range and volume of fire, the MK110 57mm (Weapon 1) had more of an impact on T-Craft survivability than the 30 mm cannon (Weapon 2) in the scenarios examined.

2. How Should the T-Craft Be Employed When a Threat Exists?

All of the scenarios in this research produced the same results with respect to the effects of escorts in relation to T-Craft survivability and number of T-Craft ashore. Having escorts present significantly increased both measures. Specifically, having more than two LCS_SWs substantially increased T-Craft survivability. Further analysis of these particular scenarios yielded the following results. When a surface and subsurface threat is present the recommended number of T-Craft is ten or more with an escort mix of: two or more LCS_SW, three or more LCS_ASW, and six or more MH-60s. With a pure surface threat, the recommended number of T-Craft is seven or more with an escort mix of two or more LCS_SW, one or more LCS_ASW, and five or more MH-60s. If there are no escorts, but a threat exists, the T-Craft should incorporate the TTP return to seabase.

Because speed appeared to be significant in each run, it is important to address as well. From the analysis, the operating speed of the T-Craft must be determined by the operating capabilities of the escorts. When a threat is present, the T-Craft should travel with its escort vehicles. Because the top speed of the LCS is 40 knots, the T-Craft should not exceed that speed. Therefore, regarding speed, the optimal operating range for the T-Craft is between 25 and 30 knots when using the LCSs as an escort. It is important to note that the recommended range is still faster than the current inventory of seabase connectors.

Finally, the shoreline threat remains a critical area in ensuring T-Craft survivability. In the scenarios examined, the LCSs could only travel within six miles of the shoreline due to their draft. The area between the shoreline and six miles out is where the semi-submersibles and swarm boats were most prevalent in each scenario. That area

also represents the region where the T-Craft transforms from SES to ACV as it transits to shore and from ACV back to SES as it transits back to the seabase. The transition times are approximately 45 minutes to one hour, leaving the T-Craft more vulnerable. This area needs further examination.

C. FOLLOW-ON WORK

The findings of this thesis are based on the modeled environment. At the time of model development, there were numerous assumptions about the T-Craft and its capabilities. In May 2010 Alion, Textron, and Umoe Mandal presented their Phase II design developments to ONR. With each presentation came better information on the performance capabilities of the T-Craft. Further studies should be developed leveraging this information to better refine the T-Craft attributes in the current model or other modeling environments to see if there are significant changes.

The scenario assumed air superiority and did not include a deep-water subsurface threat. In addition, the modeled LCS_ASW did not include its complete mix of sensors. Adding more detail to the model in the form of enemy threat and friendly capabilities may uncover more information not captured in this thesis. With that, the following are recommendations for follow-on research:

- Analysis of the impact of an air or subsurface threat in the T-Craft operating area.
- Analysis of the coastal region where the T-Craft transforms from SES to ACV to see if other vessels are needed to augment the LCS role in force protection to reduce Blue force casualties.
- Further analysis of sensors and weapon systems.
- The modeling and simulation of shore missile threats against Blue forces operating in a littoral or near littoral combat environment.
- Develop other scenarios, for example, an inter-agency scenario (i.e., U.S. military, Homeland Defense, and Red Cross) where the T-Craft is conducting operations in response to a natural disaster.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. SCENARIOS

The scenarios in this thesis were taken directly from the article *Transformable Craft Throughput: A Requirements Analysis* (Helland, Jimenez, & Rowden, 2009).

A. SOUTH AMERICA—PEACEKEEPING AND PEACE ENFORCEMENT

1. Background

The year is 2025, and the Colombian Civil War has raged in the country for sixty years. The current elected president Mario Gutierrez Pedroza assumed the presidency of Colombia after a record low voter turnout. It appears that the people of Colombia have lost total confidence in the democratic process and the Colombian Government. The Colombian economy is experiencing the worst crisis the country has seen. The level of violence in the country is unprecedented. During the past two years guerrillas and the San José Cartel has murdered approximately 1,800 public officials including town mayors, federal and state legislators, judges, and prosecutors. More than 17,000 people have been killed in 420 recorded massacres.

The San José Cartel was born from the ashes of the Medellin and Cali Cartels, which were virtually dismantled in the year 2007. In early 2012, a new drug called "magia" (*magic*) first appeared in the U.S. Months later, *magic* made its debut in the European Union and Asia. The drug is a stimulant that accelerates physical and mental states, produces euphoria, and eases physical and mental pain. In many cases, the user is prone to violent behavior. Today, the use of *magic* has reached epidemic proportions. It is estimated that in the U.S. there are more than 15 million addicts and an estimated 80 million worldwide. The death toll in the U.S. attributed directly or indirectly to the use of *magic* has surpassed 500,000 since the appearance of the drug in 2012.

With the advent of *magic*, the San José cartel has been able to establish an alliance with the Colombian insurgency movement, in particular the Revolutionary Armed Forces of Colombia (FARC). Soon after the 2013 government campaign against the rebels, the National Liberation Army (ELN) joined forces with the FARC, and the Common Front for the Liberation of Colombia (CFLC) was born. Today, the CFLC has

become the security force for the San José Cartel. The CFLC has taken advantage of increased drug revenue to build up their conventional arsenal, largely purchased from neighboring Venezuela. Last year, the annual CFLC income was estimated at over U.S. $800 million.

The current situation in Colombia has taken its toll not only on the U.S., but also in the region. The political and economic instability of the neighboring countries has ignited the formation of a series of new narco-guerrilla groups. The violence is rapidly spreading to neighboring Ecuador, Peru, and Venezuela. With their considerable arsenal and forces, the objective of the San José Cartel and the CFLC is to continue to disrupt and eventually to overthrow the Colombian Government. The CFLC desires to establish a government that will allow the San José Cartel to continue to massively export *magic* worldwide, but particularly to the United States.

2. Scenario

In the last two years, the CFLC has practically crippled the Colombian Armed Forces. In a coordinated attack, CFLC forces infiltrated four air force bases and destroyed most of the aircraft. Only the airbases at Barranquilla and Santa Maria were able to minimize the damage inflicted by the CFLC. The naval base at Puerto Tamuco was also attacked and the guerrillas seized 37 out of 41 patrol craft. Intelligence reported the possible deployment of floating mines in the ports of Buenaventura and Tamuco. Those reports were later confirmed by the sinking of the merchant ship *Tulango* after a mine explosion 37 miles NW of Buenaventura. The Colombian Army has also suffered a series of devastating blows that practically left the CFLC in control of Colombia south of the 4th parallel. In addition, the CFLC has systematically destroyed most of the transportation infrastructure west of the *Cordillera* (Andes Mountains). The few usable roads are under heavy guerrilla guard and practically unsuitable for the transportation of heavy equipment.

The United Nations Security Council has held several meetings over the instability in the region. The U.S. has sought a resolution (NSCR) calling for a U.N. peacekeeping force to restore the failed government, eliminate the CFLC and other cartels, and deal a blow to the drug trade by supporting stability and security to the

region. However, Russia, as Venezuela's ally, has vetoed these efforts alleging that "U.S. imperialists are seeking to restore their former oppressed provinces." Russia claims Venezuela is capable of leading a "Latin Partnership" capable of restoring security to the region, despite Venezuela's part in supplying the cartels.

3. Action

The U.S. intends to unilaterally insert a force capable of securing the country, destroying the drug cartels, resisting possible Venezuelan influence, and ultimately restoring a democratic government.

Elements of the 7th Special Forces Group will utilize El Dorado International Airport as an APOD to quickly enter the capital city of Bogota in order to reestablish a Colombian security force, conduct counter insurgency operations, and secure the city to enable an interim government to be established.

Conventional forces to be inserted include the Second MEB embarked on the Iwo Jima Expeditionary Strike Force, the Tenth Mountain Division, and the First Cavalry Division. The MEB will be inserted, utilizing ARG connectors near the city of Covenas. The geographic proximity to Venezuela will provide a deterrent from that country sending troops into Colombia.

Meanwhile, Army units will primarily be transported ashore via T-Craft, near the town of Tumaco on the southern coast, in order to take advantage of the highway network that originates in the area. Forces shall be staged at a sea base 50 miles offshore. Initial objectives are known or suspected cartel operation areas. Troops will drive inland to meet up with Ecuadorian troops acting as advisors and translators to U.S. forces. Utilizing these advisors to gain information on cartel operations, U.S. troops shall continue to determine cartel operation areas, secure them, and restore local law enforcement (Helland, et al., 2009).

B. SOUTH EAST ASIA – REGIONAL CONFLICT

1. Background

The Kalimantan Republic became an independent nation in October 2002, when General Gegwan Riady proclaimed that the four Indonesian provinces on Borneo were seceding from Indonesia to create a new republic. The secession was justified by claims that the Jakarta government was inadequately providing for the economic well-being of the Kalimantan people. Riady claimed specifically that the central government's failure to invest in Kalimantan infrastructure, as opposed to the enormous wealth exported from the southern island's reported vast petroleum stores. The Jakarta government, unable to counter Riady's move, grudgingly acceded to Kalimantan's declaration of independence. After the accession, the Kalimantan Republic was generally accepted internationally, including by the United States.

However, in the recent years the Kalimantan Republic has suffered a reversal in its economic fortunes since the collapse of the world petroleum market. Economic worries deepened when improved survey techniques discovered that previous estimates of Kalimantan's offshore energy reserves had been grossly overestimated. Now seriously overextended, the Riady government suspended most of its "New Kalimantan" initiatives, including a number of tourism and infrastructure-related construction and

development projects. Suspension of these projects has led to 40 percent unemployment. This unemployment and intermittent civil disturbances, including food-line riots and dramatically increased level of crime, has hit the larger cities of Kalimantan.

Riady sought financial aid from Malaysia and Brunei. But, with Kalimantan's dept now totaling nearly $12 billion, neither of its neighbors was willing to extend either outright grants or unsecured loans to the struggling nation. This denial led to public denouncements by Riady, alleging that the "affluent" north had turned its back on their "brothers to the south." Riady swore to correct the "blatant and discriminatory economic inequality" that exists between the north and south. Over the course of a few months, "One Borneo, One Nation" became not just a diplomatic theme; it also became the central focus of Kalimantan (KA) military planning.

2. Scenario

Hostilities commenced shortly after a public statement by Riady that Malaysia had been using offshore oil terminals to steal petroleum from Kalimantan fields. He stated that Kalimantan would not sit idly by as the discriminatory north stole the very resources that it had refused to help develop. He made a call on the "Iban," a Malaysian separatist movement, to help Kalimantan in the coming fight for economic equality. Immediately after the public address, two Kalimantan army divisions began using air and amphibious forces to gain footholds in Malaysia. The First Kalimantan Division (KD) landed near Kuching and began driving west through Malaysian territory. The Third KD moved into Sandakan on the east coast of Malaysia, and began driving west towards Brunei. Reportedly, KA naval forces laid sea mines in the Trusan Strait, effectively blocking Malaysian, and Brunei naval forces.

It is believed that KA forces are taking an operational pause to restructure their positions before advancing inland. Two divisions remain in the south, near the Kalimantan capital of Banjarmasin. While one is expected to remain near the capital, naval movements suggest the other may be used to reinforce units in place before the main force advances. Malaysian and Brunei forces, outnumbered by the well-equipped KA divisions, were forced to fall back to defensive positions. Two Malaysian brigades are emplaced near Bitulu, along the First KD's expected line of advance. Two additional

Malyasian brigades are near the city of Kota Kinabalu, blocking the Third KD drive towards Brunei. Two battalions of Brunei troops are located in the capital city of Bandar Seri Begawan.

Malaysia is requesting U.S. assistance in preventing further loss of territory until it can mobilize troops to remove KA forces occupied in the region. The mobilization and movement of Malaysian troops is expected to take up to 120 days.

3. Action

The U.S. will reinforce Malaysian units in order to deter further KA expedition and to support blue forces should deterrence fail. The Tenth Mountain Division will support forces near Kota Kinabalu, while the Third MEB will support forces near Bintulu. The threat of sea mines will prevent the use of the major SPODs until MCM assets can clear the restricted waterways. As such, forces will arrive via T-Craft to beach heads near friendly forces. The seabase will consist of two MPF(F) squadrons, colocated to reduce naval security presence. The MPF(F) ships will stage the U.S. divisions and sustain them and allied Malaysian and Brunei forces (Helland, et al., 2009).

APPENDIX B. PERSONALITIES AND CAPABILITIES OF AGENTS

Colombia

- Red Forces
  - Patrol boats
  - Semi-submersibles
- Friendly Forces
  - T-Craft
  - LCS Surface Package
  - LCS ASW
  - MH-60 (ASW)
  - Destroyer

Malaysia

- Red Forces
  - Patrol boats
  - Swarm boats
- Friendly Forces
  - T-Craft
  - LCS Surface Package
  - LCS ASW
  - MH-60 (Surface)
  - Destroyer

A. RED FORCES

Red force patrol boat and swarm boat information was obtained from *The Naval Institute Guide to Combat Fleets of the World*, (15th ed.) (Wertheim, 2007). Semi-submersible information was obtained from the Global Security.org Web site at http://www.globalsecurity.org/military/world/para/spss.htm.

1. Colombia

a. Patrol Boat

Weapon	Range	Pk: Short/ Mid/ Long	Rounds
C-802 SSM	120km	.9/ .5/ .3	4
76mm OTO	30km	.75/ .3 /.03	3000

The patrol boat used in the Colombia scenario is modeled after the Venezuelan Navanita class patrol boat. The boats patrol the coastal regions as the first

line defense of the drug cartels. The T-Craft is the primary target of this vessel. When a T-Craft is detected, the patrol craft increases its speed from the cruising speed of 25 knots to 35 knots in order to attack the T-Craft. If the patrol force encounters the LCS, its secondary target, the patrol craft will continue in the attack. The detection range of this vessel is 20 nm and the classification range is 15 nm.

b. Semi-submersibles

Weapon	Range	Pk	Rounds
Explosive	3704m	.9	1

The semi-submersibles in this scenario are modeled after a typical Colombian semi-submersible drug boat. These boats can hold up to ten tons of cocaine. For the purpose of this scenario, explosives replace the cocaine, representing an improvised explosive device along the shoreline. The semi-submersibles are guided by remote control and remain in the water until they explode or are destroyed. The T-Craft is the primary target of the semi-submersible. If the remote signal is lost, semi-submersibles are capable of leaving the coastline and therefore representing a threat to the LCS.

2. Malaysia

a. Patrol Boat

Weapon	Range	Pk: Short/ Mid/ Long	Rounds
C-802 SSM	120km	.9/ .5/ .3	4
76mm SS	30km	.75/ .3/ .03	3000
40mm SA	12500m	.75/ .3/ .03	3000

The patrol boat used in the Malaysia scenario is modeled after the French PR-72 560 class patrol boat. The boats patrol the coastal regions as the main security force. The T-Craft is the primary target of this vessel. When a T-Craft is detected, the patrol craft increase its speed from the cruising speed of 25 knots to 35 knots in order to

attack the T-Craft. If the patrol force encounters the LCS, its secondary target, the patrol craft will continue in the attack. The detection range of this vessel is 20 nm and the classification range is 15 nm.

b. Swarm

Weapon	Range	Pk: Short/ Mid/ Long	Rounds
25mm	120km	.75/ .4/ .1	4
.50 cal X 4	1000m	.9/ .3/ .1	1000

The swarm boat in the Malaysia scenario is modeled after the Pilipino FELIX APOLINARIO patrol boat. The boats patrol very close to the shoreline looking for weak targets. The T-Craft is the primary target of this vessel. When a T-Craft is detected, the patrol craft increases its speed from the cruising speed of 25 knots to 35 knots in order to attack the T-Craft. The swarm craft has a personality setting to come together (swarm) as they attack the T-Craft. If the swarm force encounters the LCS, they will evade and return to a safe location. Once the LCS leaves the area the swarm crafts begin to patrol again. The detection and classification range of this vessel is 20 nm.

B. BLUE FORCES

With the exception of the T-Craft, blue force data was obtained from *Jane's Fighting Ships 2005 – 2006* (2005).

1. T-Craft

Weapon	Range	Pk: Short/ Mid/ Long	Rounds
Mk110 57mm	17000m	NOLH	1000
30mm cannon	6800m	NOLH	3000

The T-Craft has the mission of transporting sustainment ashore. As the T-Craft encounters enemy forces, it will attempt to evade the threat. When the T-Craft encounters enemy patrol boats, the T-Craft will speed up in an attempt to outrun the enemy force. The T-Craft is also prone to stay close to other friendly forces in hostile territory. In

contrast, when semi-submersibles are encountered, the T-Craft will slow down in an attempt to destroy the threat or maneuver around it. The speed of the T-Craft is varied by the NOLH and its detection and classification range is 20 nm.

2. Littoral Combat Ships

Weapon	Range	Pk: Short/ Mid/ Long	Rounds
NLOS-LS	74080m	.87/ .5/ .03	45
MK110 57mm	17000m	.9/ .7/ .5	1000
30mm cannon	6800m	.9/ .8/ .7	3000
RAM	4828m	.8/ .5/ .2	45

The Littoral Combat ship surface package has the primary mission of providing security for the T-Craft. The LCS_SW patrols at 20 knots to and from the shore. Due to its draft, the LCS_SW can only come within six nm of the shoreline. The primary target of the LCS is enemy patrol boats. Once enemy vessels are detected, the LCS_SW increases speed to 40 knots in order to engage and eliminate the enemy. The LCS do not detect the semi-submersibles that are located along the shoreline due to the constraints of only coming within six nm of the shore. As semi-submersibles drift out of range, the LCS can then detect them. Once detected, the LCS will attempt to destroy the semi-submersible. The detection and classification range of the LCS_SW package is 30 nm.

Weapon	Range	Pk: Short/ Mid/ Long	Rounds
MK110 57mm	17000m	.9/ .7/ .5	1000
30mm cannon	6800m	.9/ .8/ .7	3000
RAM	4828m	.8/ .5/ .2	45
.50 cal	1000m	.9/ .3/ .1	5000

The Littoral Combat ship anti-submarine warfare package has the primary mission of providing security for the T-Craft. The LCS_ASW patrols at 20 knots to and from the shore. Due to its draft, the LCS_ASW can only come within six nm of the shoreline. The primary target of the LCS is enemy patrol boats. Once enemy vessels are detected, the LCS_ASW increases speed to 40 knots in order to engage and eliminate the

enemy. The LCS do not detect the semi-submersibles that are located along the shoreline due to the constraints of only coming within six nm of the shore. As semi-submersibles drift out of range, the LCS then can detect them. Once detected, the LCS will attempt to destroy the semi-submersible. The detection and classification range of the LCS_ASW package is 30 nm.

3. Destroyer

Weapon	Range	Pk: Short/ Mid/ Long	Rounds
Harpoon	240km	.9/ .2/ .03	16
Mk110 57mm	17000m	.9/ .8/ .7	1000
127mm	14816m	.9/ .3/ .1	500

The destroyer is located at the seabase and has the primary mission of defending the seabase. In addition, the destroyer also provides over watch to sustainment operations going ashore. If an enemy vessel comes within range of the seabase or the destroyer, the destroyer will fire on that vessel.

4. MH-60

Weapon	Range	Pk: Short/ Mid/ Long	Rounds
Hellfire	14816m	1/ .5/ .3	8
Torpedo	14816m	.9/ .5/ .2	3

The MH-60 patrols the area looking for enemy threats. If the MH-60 comes in contact with enemy patrol craft the MH-60 will stand off until LCSs arrive. The MH-60 does not engage the enemy patrol vessels. If the MH-60 detects the swarm or semi-submersibles, they will attempt to destroy them with their organic weapons systems. The MH-60 patrols at 150 km and engages the enemy at 140 km. Its detection and classification range is 20 nm.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C. MODEL DESIGNS

A. EXPLORATORY DESIGN

The table below lists the input ranges for the exploratory design. Controllable factors are in blue and noise factors are in red. The design was set up to explore the model and ensure its realism. This design was developed using the NOLH design and consisted of 18 factors and 129 design points.

Factors	Value Range	Description
Number of T-Craft	**5 – 10**	**Number of T-Craft in a given design run**
T-Craft Speed in knots	**35 – 55**	**T-Craft speed in a given run**
Number of LCS_SW	**1 – 5**	**Number of LCS_SW in a given design run**
Number of LCS_ASW	**1 – 5**	**Number of LCS_ASW in a given design run**
Number of MH-60	**1 – 5**	**Number of MH-60 in a given design run**
T-Craft DetR	**185m – 92600m**	**Detection range of the T-Craft in a given design run**
LCS_SW DetR	**185m – 92600m**	**Detection range of the LCS_SW in a given design run**
LCS_ASW DetR	**185m – 92600m**	**Detection range of the LCS_ASW in a given design run**
MH-60 DetR	**185m – 92600m**	**Detection range of the MH-60 in a given design run**
NLOS Pk	**0 – 1**	**Probability of kill associated with the NLOS weapon system**
Mk110 57mm	**0 – 1**	**Probability of kill associated with the Mk110 weapon system**
30mm Pk	**0 – 1**	**Probability of kill associated with the 30mm weapon system**
RAM Pk	**0 – 1**	**Probability of kill associated with the RAM weapon system**
.50 cal Pk	**0 – 1**	**Probability of kill associated with the .50 cal weapon system**
Hellfire Pk	**0 – 1**	**Probability of kill associated with the Hellfire weapon system**
Torpedo Pk	**0 – 1**	**Probability of kill associated with the**

		torpedo weapon system
Red Patrol Boats	***10 – 30***	***Number of red patrol boats in a given run***
Semi-submersibles	***0 – 50***	***Number of semi-submersibles in a given run***
Semi-submersible DetR	***0 – 463m***	***Detection range of the semi-submersible in a given run***

B. PRELIMINARY DESIGN

Once adjustments were made to the model, a preliminary design was developed to further explore the simulation model. The preliminary design was created to provide a more detailed look at each scenario after the refinement of the exploratory design. This design consisted of 11 factors and 257 design points. The format is the same as above.

Factors	**Value Range**	**Description**
Number of T-Craft	**5 - 11**	**Number of T-Craft in a given design run**
Active Weapon	**1,2, 3(Both)**	**Weapon used in a given design run**
T-Craft Speed in knots	**20 – 55**	**T-Craft speed in a given run**
LCS_SW	**1 – 30**	**Number of LCS_SW in a given design run**
LCS_ASW	**1 – 5**	**Number of LCS_ASW in a given design run**
Destoryer	**1 – 3**	**Number of Destroyer in a given design run**
MH-60	**1 - 10**	**Number of MH-60 in a given design**
Mk110 57mm Pk	**0.5 – 1**	**Probability of kill associated with the MK110**
30mm Pk	**0.5 – 1**	**Probability of kill associated with the 30mm**
Red Patrol	***0 - 10***	***Number of red patrol boats in a given design run***
Semi-submersible (Colombia scenario)	***0 – 5***	***Number of semi-submersibles in a given design run***
Swarm (Malaysia scenario)	***5 – 15***	***Number of swarm boats in a given design run***

C. FIRST STAGE DESIGN

The table below lists the input ranges for the design addressing the first question in this thesis. The design was set up to explore the different combinations of the T-Craft being armed, unarmed, escorted, and not escorted. The default escort setting in this model is: five LCS_SW, two LCS_ASW, two Destroyers, and four MH-60s.

Factor	Value Range	Description
Number of T-Craft	**5 – 11**	**The number of T-Craft in a given design run**
T-Craft Armed	**0, 1**	**Binary variable to set the weapons on (1) or off (0)**
Alt Waypoint	**0, 1**	**TTP for the T-Craft: (0) – T-Craft goes to shore; (1) T-Craft returns to seabase**
Escorts Vessels	**0, 1**	**Determines if the T-Craft is escorted in a given run.** **(1) – yes; (0) - no**
T-Craft Speed in knots	**20 – 55**	**T-Craft speed varies for each design run**
Red Patrol Boats	***5 – 15***	***The number of red patrol boats in a given design run***
Red-semisubmersibles (Colombia scenario)	***0 – 5***	***The number of semi-submersibles in a given design run***
Swarm (Malaysia scenario)	***0 – 15***	***The number of swarm boats in a given design run***

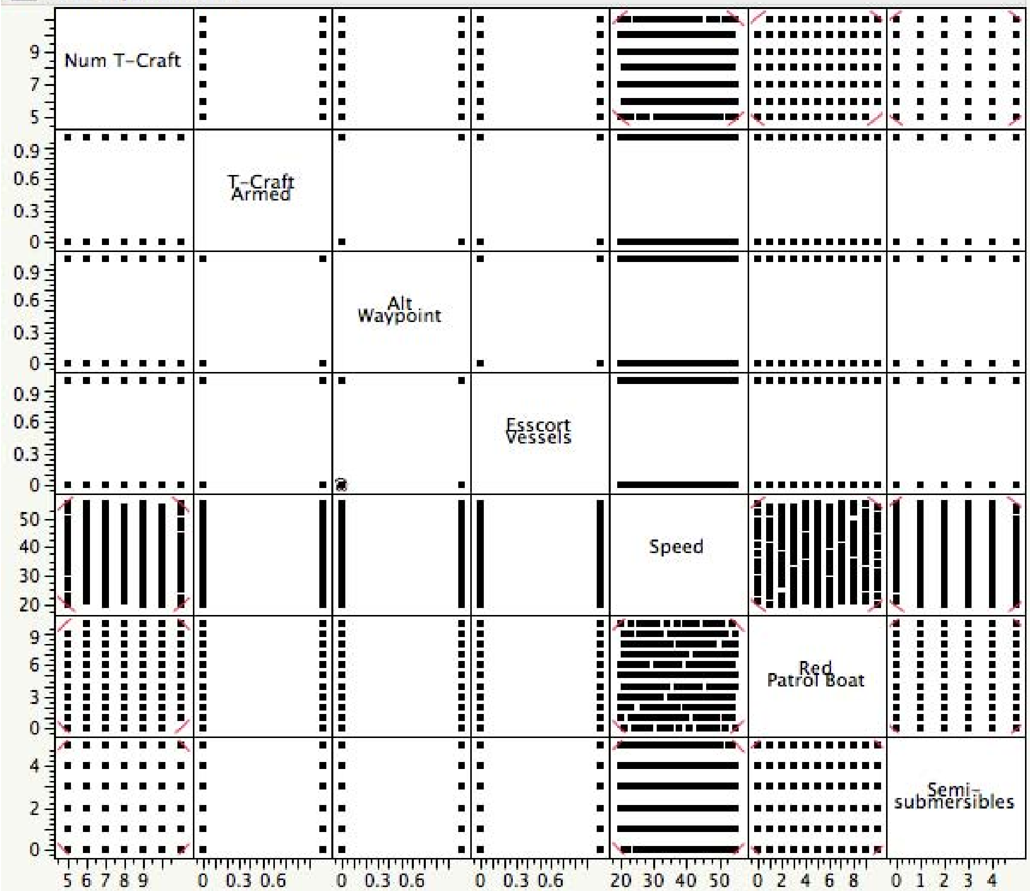
Below is the correlation matrix and scatter plot of the Colombia first stage design, which shows the filling properties of the NOLH. Factors are listed along the diagonal.

Correlations

	Num T-Craft	T-Craft Armed	Alt Waypoint	Esscort Vessels	Speed	Red Patrol Boat	Semi-submersibles
Num T-Craft	1.0000	0.0109	0.0152	0.0370	-0.0140	0.0175	-0.0051
T-Craft Armed	0.0109	1.0000	0.0175	0.0019	0.0059	0.0186	-0.0019
Alt Waypoint	0.0152	0.0175	1.0000	-0.0136	0.0112	0.0373	0.0240
Esscort Vessels	0.0370	0.0019	-0.0136	1.0000	0.0281	0.0226	-0.0434
Speed	-0.0140	0.0059	0.0112	0.0281	1.0000	-0.0040	-0.0122
Red Patrol Boat	0.0175	0.0186	0.0373	0.0226	-0.0040	1.0000	0.0071
Semi-submersibles	-0.0051	-0.0019	0.0240	-0.0434	-0.0122	0.0071	1.0000

The correlations are estimated by REML method.

Scatterplot Matrix



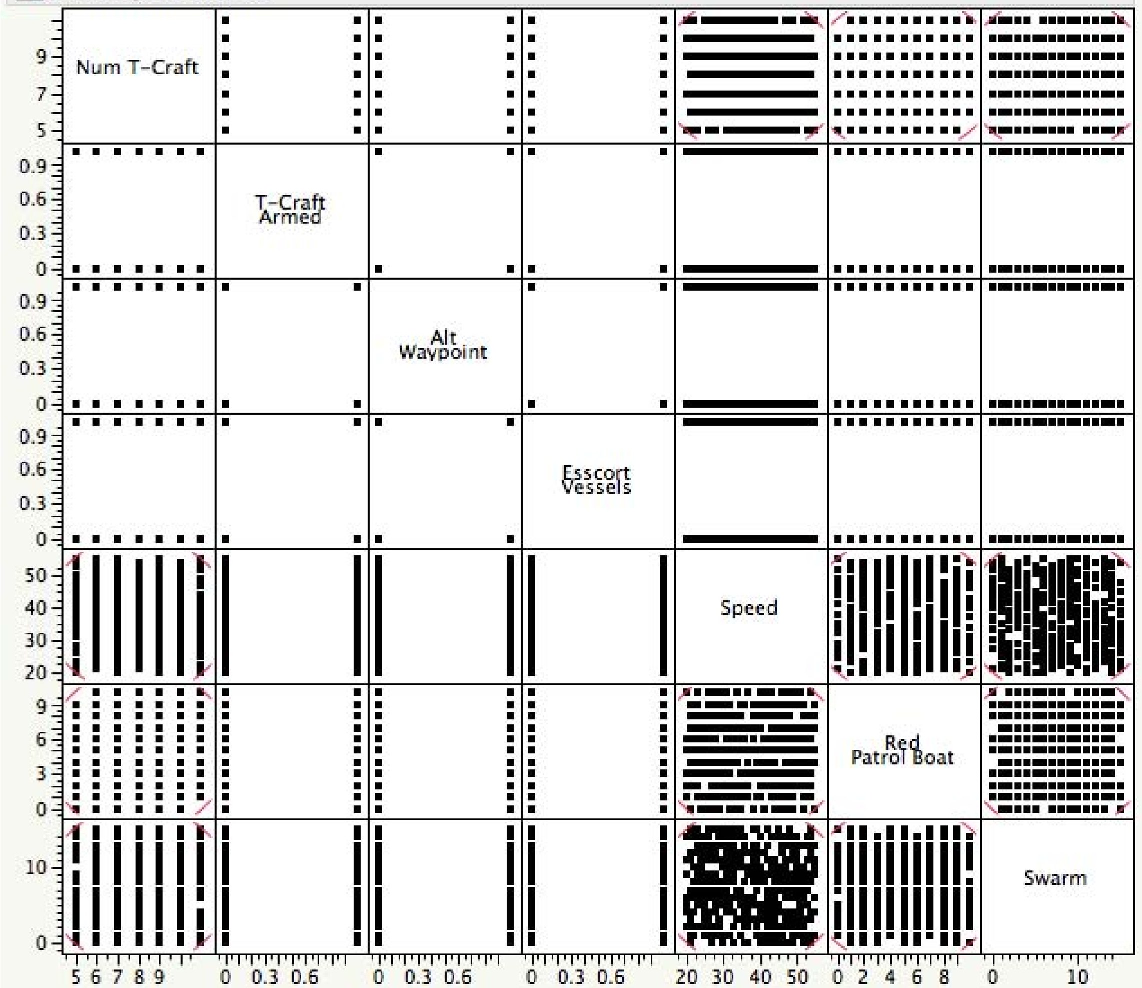
Below is the correlation matrix and scatter plot of the Malaysia first stage design, which shows the filling properties of the NOLH. Factors are listed along the diagonal.

Correlations

	Num T-Craft	T-Craft Armed	Alt Waypoint	Esscort Vessels	Speed	Red Patrol Boat	Swarm
Num T-Craft	1.0000	0.0109	0.0152	0.0370	-0.0140	0.0175	-0.0025
T-Craft Armed	0.0109	1.0000	0.0175	0.0019	0.0059	0.0186	-0.0007
Alt Waypoint	0.0152	0.0175	1.0000	-0.0136	0.0112	0.0373	0.0190
Esscort Vessels	0.0370	0.0019	-0.0136	1.0000	0.0281	0.0226	-0.0311
Speed	-0.0140	0.0059	0.0112	0.0281	1.0000	-0.0040	0.0004
Red Patrol Boat	0.0175	0.0186	0.0373	0.0226	-0.0040	1.0000	-0.0043
Swarm	-0.0025	-0.0007	0.0190	-0.0311	0.0004	-0.0043	1.0000

The correlations are estimated by REML method.

Scatterplot Matrix



D. SECOND STAGE DESIGN

The second stage of the design was set up to determine the best employment method of the T-Craft. The stage two design consisted of 11 factors and 513 design points created by the NOLH.

Factors	Value Range	Description
Number of T-Craft	**5 - 11**	**Number of T-Craft in a given design run**
Active Weapon	**1, 2, 3 (Both)**	**Weapon used in a given design run**
T-Craft Speed in knots	**20 – 55**	**T-Craft speed in a given design run**
LCS_SW	**1 – 10**	**Number of LCS_SW in a given design run**
LCS_ASW	**1 – 5**	**Number of LCS_ASW in a given design run**
Destoryer	**1 – 3**	**Number of Destroyer in a given design run**
MH-60	**1 - 10**	**Number of MH-60 in a given design run**
Mk110 57mm Pk	**0.5 – 1**	**Probability of kill associated with the MK110**
30mm Pk	**0.5 – 1**	**Probability of kill associated with the 30mm**
Red Patrol	***0 - 10***	***Number of red patrol boats in a given design run***
Semi-submersible (Colombia scenario)	***0 – 5***	***Number of semi-submersibles in a given design run***
Swarm (Malaysia scenario)	***0 – 15***	***Number of swarm boats in a given design***

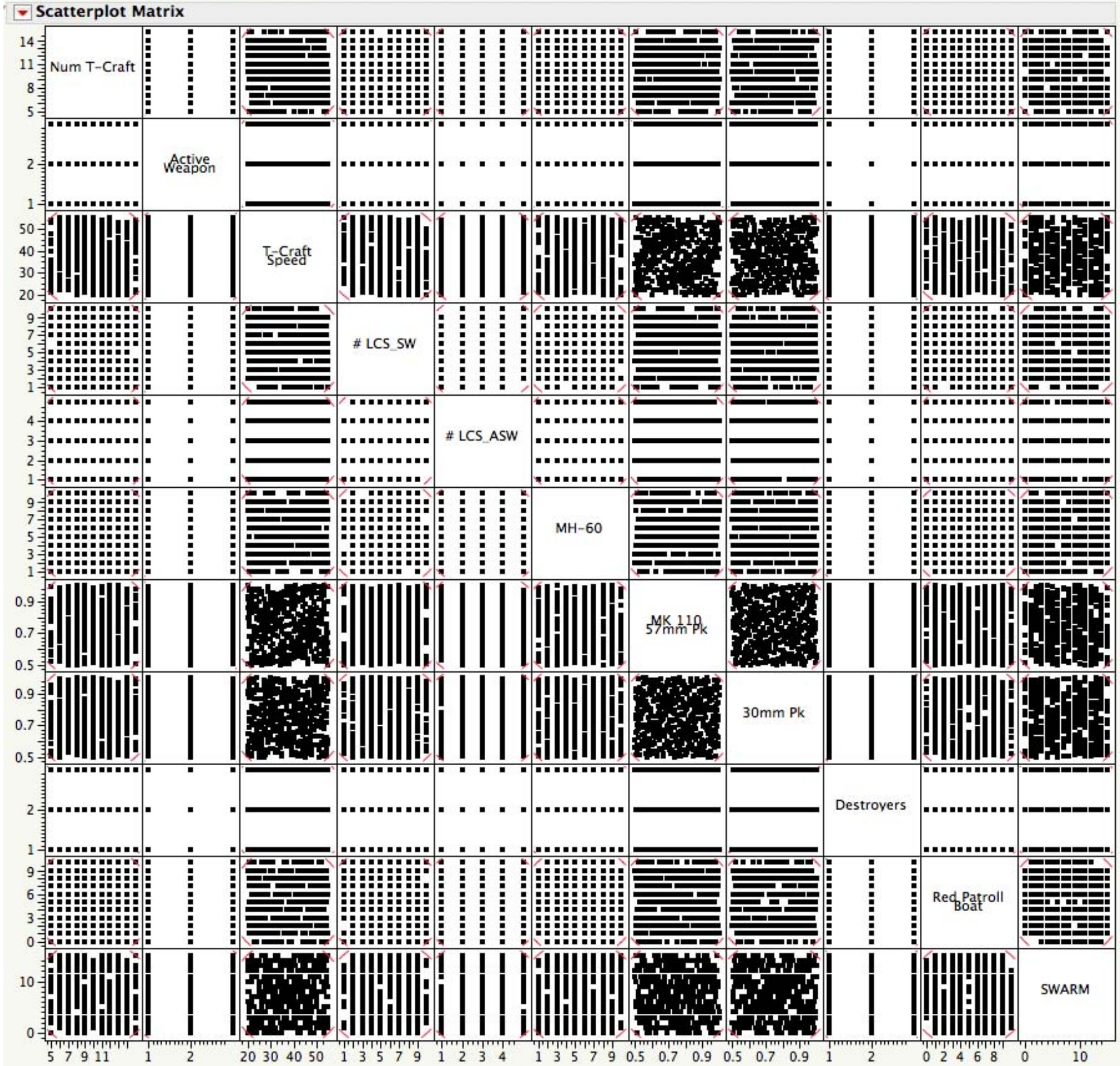
The figure below shows the correlation matrix and scatter plots of the Malaysia scenario. It illustrates the near orthagonality and space-filling properties of the NOLH design.

Correlations

	Num T-Craft	Active Weapon	T-Craft Speed	# LCS_SW	# LCS_ASW	MH-60	MK 110 57mm Pk	30mm Pk	Destroyers	Red Patroll Boat	SWARM
Num T-Craft	1.0000	-0.0122	-0.0029	-0.0010	-0.0006	-0.0028	0.0043	0.0054	0.0394	-0.0130	0.0034
Active Weapon	-0.0122	1.0000	0.0190	-0.0197	0.0111	-0.0145	0.0181	-0.0083	-0.0465	0.0037	-0.0410
T-Craft Speed	-0.0029	0.0190	1.0000	0.0036	-0.0095	-0.0079	-0.0030	-0.0001	-0.0130	0.0112	-0.0071
# LCS_SW	-0.0010	-0.0197	0.0036	1.0000	0.0108	-0.0013	-0.0010	-0.0054	-0.0021	0.0003	0.0033
# LCS_ASW	-0.0006	0.0111	-0.0095	0.0108	1.0000	-0.0252	-0.0090	0.0013	0.0022	-0.0130	0.0033
MH-60	-0.0028	-0.0145	-0.0079	-0.0013	-0.0252	1.0000	-0.0036	-0.0056	-0.0457	0.0136	-0.0003
MK 110 57mm Pk	0.0043	0.0181	-0.0030	-0.0010	-0.0090	-0.0036	1.0000	0.0000	-0.0013	-0.0073	-0.0049
30mm Pk	0.0054	-0.0083	-0.0001	-0.0054	0.0013	-0.0056	0.0000	1.0000	-0.0384	-0.0109	-0.0053
Destroyers	0.0394	-0.0465	-0.0130	-0.0021	0.0022	-0.0457	-0.0013	-0.0384	1.0000	0.0347	-0.0082
Red Patroll Boat	-0.0130	0.0037	0.0112	0.0003	-0.0130	0.0136	-0.0073	-0.0109	0.0347	1.0000	-0.0002
SWARM	0.0034	-0.0410	-0.0071	0.0033	0.0033	-0.0003	-0.0049	-0.0053	-0.0082	-0.0002	1.0000

The correlations are estimated by REML method.

Scatterplot Matrix



THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Abbott, B.P. (2008, March). *Littoral Combat Ship (LCS) Mission Packages: Determining the Best Mix.* Master's Thesis. Monterey, CA: Naval Postgraduate School.

Anderson, S. E., Barnard, T. A., O'Briasky, J. S., Ray, D. E., & Wilson, R. A. (2009a). *Operational Logistics in the Future Sea Force*. Working Paper. Monterey, CA: Naval Postgraduate School.

Anderson, M. A., Galligan, D. P., Lauren, M. K., & McIntosh, G. C. (2007). *MANA (Map Aware Non-Uniform Automata), Version 4 User Manual.* New Zealand: Operations Analysis Section, Defense Technology Agency.

Anderson, S., & Triola, L. (2009b). *T-craft: Critical Design and Operation Issues Associated with the Sea-Basing Connector Role.* Working Paper. Monterey, CA: Naval Postgraduate School Systems Engineering Department.

Anderson, S., Triola, L. C., & Scalzo, R. (2009c). *T-craft: Notional Mission Frame Work.* Working Paper. Monterey, CA: Naval Postgraduate School Systems Engineering Department.

Bonsel, M., & Schrady, D. (2004). *JELO: A Model of Joint Expeditionary Logistics Operations.* (Technical Report No. NPS-OR-05-001) Monterey, CA: Naval Postgraduate School Systems Engineering Department.

Chang, J. (2008). T-Craft Brief to the High Speed Sealift/Agile Port Action Officer Group. Washington, DC: *ONR Ship Design Manager.*

Cioppa, T. M. (2002) *Efficient Nearly Orthogonal and Space-filling Experimental Designs for High-dimensional Complex Models.* Dissertation. Monterey, CA: Naval Postgraduate School.

Cioppa, T. M., & Lucas, T. W. (2007) Efficient Nearly Orthogonal and Space-Filling Latin Hypercubes. *Technometrics, 49*(1), 45–55.

Cioppa, T. M., Lucas, T. W., & Sanchez, S. M. (2004) Military Applications of Agent Based Simulations. *Proceedings of the 2004 Winter Simulation Conference.* Monterey, CA: Naval Post Graduate School.

Conway, J. T. (2006). *Commandant's Planning Guidance* [34th Commandant of The Marine Corps, Commandant's Planning Guidance]. Washington, D.C.: Headquarters Marine Corps.

Dale, B.P. (2010, March). *A Rough Order of Magnitude (ROM) Life Cycle Cost Estimate (LCCE) of the Transformable Craft (T-Craft) Concept.* Master's Thesis. Monterey, CA: Naval Postgraduate School.

Department of Defense (DoD) (2005). *Seabasing Joint Integrating Concept.* Washington, D.C.: Author.

Doyle, Erik (2008). Joint Seabasing Brief to The MROC. Quantico, VA: Marine Corps Combat Development Command Concepts & Plans.

Global Security.org (2006a). *Landing Craft Air Cushion (LCAC).* Retrieved Month Year from http://www.globalsecurity.org/military/systems/ship/lcac.htm

Global Security.org (2006b). *Sea Base Connector Transformable Craft.* Retrieved Month Year from http://www.globalsecurity.org/military/systems/ship/t-craft.htm

Global Security.org (2007). *Maritime Prepositioning Force (Future).* Retrieved from http://www.globalsecurity.org/military/systems/ship/mpf-f.htm

Global Security.org (2008). *Littoral Combat Ship (LCS).* Retrieved from http://www.globalsecurity.org/military/systems/ship/lcs.htm

Global Security.org (2008). *Littoral Combat Ship Specifications.* Retrieved from http://www.globalsecurity.org/military/systems/ship/lcs-specs.htm

Helland, M. C., Jimenez, R., & Rowden, B. J. (2009). *Transformable Craft Throughput: A Requirements Analysis*. (Naval Postgraduate School) Monterey, CA: Naval Postgraduate School Systems Engineering Department.

Hellard, M., Paulo E., & Rowden, B. J. (2008). *Assessing the Requirements for the Transformable Craft: A framework for Analyzing Game Changing Capabilities*. Working Paper. Monterey, CA: Naval Postgraduate School Systems Engineering Department.

Jane's Information Group Limited (2005). *Fighting Ships 2005–2006.* United Kingdom: Thanet Press.

JMP Statistical Discovery Software, Version 8.0.1 (JMP 8) (2009). Cary, NC: SAS Institute, Inc.

Lundquist, E. H. (2005). Protecting the Seabase. *Marine Corps Gazette, 89*(3), 31.

Marine Corps Combat Development Center (MCCDC) (1996). *Operational Maneuver From the Sea.* Quantico, VA: Marine Corps Combat Development Center.

Marine Corps Combat Development Command (MCCDC) (1997). *Ship to Objective Manuever*. Quantico, VA: Marine Corps Combat Development Center.

Marine Corps Combat Development Command (MCCDC) (2009). *Seabasing for the Range of Military Operations.* Quantico, VA: Marine Corps Combat Development Command.

Montgomery, D. C., Peck, E. A., & Vining, G. G. (2006). *Introduction to Linear Regression Analysis* (4th ed.). Hoboken, NJ. John Wiley & Sons, Inc.

National Defense Research Institute (RAND) (2007). *Warfighting And Logistics Support of Joint Forces From The Sea Base.* Retrieved from http://www.rand.org.

Office of Naval Research (ONR) (2005). *Broad Agency Announcement 05-020* (Technical Report No. 05-020). Arlington, VA: Author.

Office of The Chief of Naval Operations (CNO) (2006). *Seabasing Logistics Enabling Concept* (Publication No. OPNAV N42). Arlington, VA: Office of The Chief of Naval Operations.

U.S. Marine Corps. (2009) *Maritime Prepositioning Force (Future).* Retrieved from http://hqinet001.hqmc.usmc.mil/AVN/asl/Avionics/Briefs/MPF%20(F).pdf

Wertheim, E. (2007). *The Naval Institute Guide to Combat Fleets of the World* (15th ed.) . Annapolis, MD: Naval Institute Press.

Wilson, R.A. (2005), T-Craft Technical Information Sheet for EW10. Washington, DC: The Office of Naval Research.

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California

3. Mrs. Kelly Cooper
   Office of Naval Research
   Washington, D.C.

4. CAPT Doug Otte, USN
   Naval Postgraduate School
   Monterey, California

5. CAPT Jeff Kline, USN(Ret.)
   Naval Postgraduate School
   Monterey, California

6. CDR Chris Davis
   OPNAV N853
   Washington, D.C

7. Mr. Edward J. Lesnowicz, Col, USMC (Ret.)
   Naval Postgraduate School
   Monterey, California

8. Mr. Eugene Paulo
   Naval Postgraduate School
   Monterey, California

9. Commanding General, Training and Education Command
   MCCDC, Code C46
   Quantico, Virginia

10. Director, Marine Corps Research Center
    MCCDC, Code C406C
    Quantico, Virginia

11. Marine Corps Tactical Systems Support Activity (Attn: Operations Officer)
    Camp Pendleton, California

12. Director, Operations Analysis Division
Code C19, MCCDC
Quantico, Virginia

13. Marine Corps Representative
Naval Postgraduate School
Monterey, California

14. MCCDC OAD Liaison to Operations Research Department
Naval Postgraduate School
Monterey, California